

**A CRITICAL REVIEW OF THE CURRENT STATE OF FORENSIC SCIENCE KNOWLEDGE AND ITS
INTEGRATION IN LEGAL SYSTEMS**

by

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To HIM who believed in me

To HIM who supported me. More than I deserved

To HIM who helped me, more than I can ever repay

To HIM who provided me with knowledge and wisdom

All the Glory to GOD

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Summary

Forensic science has a significant historical and contemporary relationship with the criminal justice system. It is a relationship between two disciplines whose origins stem from different backgrounds. It is trite that effective communication assist in resolving underlying problems in any given context. However, a lack of communication continues to characterise the intersection between law and science.

As recently as 2019, a six-part symposium on the use of forensic science in the criminal justice system again posed the question on how the justice system could ensure the reliability of forensic science evidence presented during trials. As the law demands finality, science is always evolving and can never be considered finite or final. Legal systems do not always adapt to the nature of scientific knowledge, and are not willing to abandon finality when that scientific knowledge shifts.

Advocacy plays an important role in the promotion of forensic science, particularly advocacy to the broader scientific community for financial support, much needed research and more testing. However, despite its important function, advocacy should not be conflated with science. The foundation of advocacy is a cause; whereas the foundation of science is fact.

The objective of this research was to conduct a qualitative literature review of the field of forensic science; to identify gaps in the knowledge of forensic science and its integration in the criminal justice system. The literature review will provide researchers within the field of forensic science with suggested research topics requiring further examination and research. To achieve its objective, the study critically analysed the historical development of, and evaluated the use of forensic science evidence in legal systems generally, including its role regarding the admissibility or inadmissibility of the evidence in the courtroom.

In conclusion, it was determined that the breadth of forensic scientific knowledge is comprehensive but scattered. The foundational underpinning of the four disciplines, discussed in this dissertation, has been put to the legal test on countless occasions. Some gaps still remain that require further research in order to strengthen the foundation of the disciplines. Human influence will always be present in examinations and interpretations and will lean towards subjective decision making.

Statement by Candidate

I declare "A CRITICAL REVIEW OF THE CURRENT STATE OF FORENSIC SCIENCE KNOWLEDGE AND ITS INTEGRATION IN LEGAL SYSTEMS" is my own work and that all the sources that I have used or quoted have been indicated and acknowledged by means of complete references.

I further declare that I have not previously submitted this work or part of it, for examination at Unisa for another qualification or at any other higher education institution.

_____ Signed _____

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CHAPTER 1 Introduction to the study

1.1 Background

Crime is neither a local nor a national problem, but rather a common trend internationally. Regardless where it is committed, crime remains a threat to the fundamental rights of any individual. Some of the pertinent fundamental rights recognised in democratic countries include the right of freedom and liberty, the right to privacy, the right to life, and the right to dignity. Fundamental rights are as a set of legal protections or safeguards in the context of a democratic legal system based on the rule of law. Although many fundamental rights are generally considered human rights, the classification of rights as fundamental denotes specific legal tests that courts use to determine the conditions under which these rights may be limited. Legal systems themselves are bound by the same set of basic, fundamental, or inalienable rights. One widely recognised example of a well-established democratic system is that of the United States of America (USA), whose “Declaration of Independence” was adopted by United States Congress on 4 July 1776, written by Thomas Jefferson, who stated that:¹

“We hold these truths to be self-evident, that all men are created equal, that they are endowed by their Creator with certain unalienable Rights that among these are Life, Liberty and the pursuit of Happiness.”

A continuation of these rights was ratified with the first ten amendments adopted on 15 December, 1791, when the Bill of Rights was incorporated into the Constitution of the USA.² With these rights, authorities developed legislation to protect citizens against any form of constraint not caused by nature. By design, it also provided rights for persons accused of committing any criminal offence. The 6th Amendment to the Constitution stipulates that:

“In all criminal prosecutions, the accused shall enjoy the right to a speedy and public trial by an impartial jury of the state and district wherein the crime shall have been committed, which district shall have been previously ascertained by law, and to be informed of the nature and cause of the accusation; to be confronted with the witnesses against him; to

¹ Declaration of Independence: United States History <http://www.ushistory.org/declaration/document/> (Date of use: 18 July 2018).

² Constitution, United States of America, U. S. Const. art. IV, § 3. 17 September 1787.

have compulsory process for obtaining witnesses in his favor; and to have the assistance of counsel for his defense.”³

Many other democratic countries have similar constitutional rights, often incorporated into Bills of Rights, with strong emphasis on procedural rights and processes in terms of which suspects will be accosted, the crime investigated, criminal hearings held, the accused prosecuted and the wrongly accused acquitted. However, the success of a criminal justice system ultimately depends on human involvement, which often proves to be fallible and sometimes subjective.⁴ Any such mistakes, originating from investigating the crime, searching crime scenes, or insufficient preparation for hearings due to ignorance, may lead to technical inconsistencies whereby the guilty may be acquitted. On the other hand, arrogance and lies may lead to the conviction of the innocent. In both instances, the rights of either the victim or the innocent are violated if the criminal justice system is not built on a solid foundation of checks and balances.

1.2 Problem statement and rationale for the study

Forensic science has a significant historical and contemporary relationship with the criminal justice system. It is a relationship between two disciplines whose origins stem from different backgrounds. It is trite that effective communication assist in resolving underlying problems in any given context. However, a lack of communication continues to characterise the intersection between law and science. In some jurisdictions, such as the United States of America and the United Kingdom, the relationship between law and science seems to be a tenuous and complex one due to many omissions and examples of unethical, unprofessional, and often immoral conduct within the forensic profession.

³ National Archives “*The Bill of Rights: A Transcription*” Transcription of the 1789 Joint Resolution of Congress Proposing 12 Amendments to the U.S. Constitution. <https://www.archives.gov/founding-docs/bill-of-rights-transcript#toc-transcription-of-the-1789-joint-resolution-of-congress-proposing-12-amendments-to-the-u-s-constitution> (Date of use: 29 December 2019).

⁴ National Institute of Justice “Wrongful Convictions and DNA Exonerations: Understanding the Role of Forensic Science” https://nij.gov/journals/279/Pages/wrongful-convictions-and-dna-exonerations.aspx?utm_source=eblast-govdelivery&utm_medium=email&utm_campaign=nijjournal (Date of use: 18 July 2018).

As recently as 2019, a six-part symposium on the use of forensic science in the criminal justice system again posed the question on how the justice system could ensure the reliability of forensic science evidence presented during trials.⁵ Experts on the panel argued a number of key points explaining the “disconnect” between law and science. The arguments circled back to the different foundational backgrounds between legal professionals and scientists. Science and the law have both divergent and common goals, sometimes leading to conflict between the practices of the two professions that are supposed to work together very closely in the criminal justice context. While science may search for a comprehensive understanding of a problem or a phenomenon, which develops through a collective process involving an array of scientists, the legal profession may want to resolve a focused legal dispute in a timely, predictable and procedural manner. Scientists and legal professionals also differ with regard to their respective training and even temperament. Legal professionals often want scientists to be firm and concise, to a point where they expect a hundred per cent certainty, which scientists cannot provide. The law also demands finality, but science is always evolving and can never be considered finite or final. Legal systems do not always adapt to the nature of scientific knowledge, and are not willing to abandon finality when that scientific knowledge shifts.

Advocacy plays an important role in the promotion of forensic science, particularly advocacy to the broader scientific community for financial support, much needed research and more testing. However, despite its important function, advocacy should not be conflated with science. The foundation of advocacy is a cause; whereas the foundation of science is fact. Betty Layne DesPortes, past President of the American Academy of Forensic Science, stated the following in her February 2018 president’s address at the AAFS meeting in Seattle:

“Advocacy has a predetermined goal and seeks the most persuasive path to achieve that goal, selectively presenting facts to support an argument. Science has no predetermined goal. It follows the path determined by the facts. Science is a method, a way of gaining knowledge and explaining events or conditions through testing and factual observation. By casting forensic science in an advocacy role, the reporters’ perception misconstrues the true foundation of forensic science and

⁵ Balko R “How do we reconcile law and science” 2019-08-06 *Washington Post*.

limits its efficacy. The reporters' question made it clear that forensic science is well known, but not well understood. Forensic science has a communication problem.”⁶

These pressures often place scientists in a difficult position to “translate” the science and scientific findings into concepts that are accessible and understandable in judicial proceedings involving lay persons. It may lead to a misinterpretation of scientific testimony when cited or referred to out of context during subsequent or appellate hearings. Originally, as will be discussed in this dissertation, forensic scientists considered evidence without regard to the admissibility or inadmissibility of the evidence, whereas legal professionals had to make a clear distinction between the two.

The locus of the problem with forensic science communication can be traced back to the profession itself. Traditional forensic experts are not always scientists or may lack a proper scientific foundation or they may also not be statisticians or may lack statistical knowledge. Legal professionals, however, expect the forensic expert to know it all. Forensic scientists may also not have kept abreast of new scientific developments. Although some scientists continue to seek direction and guidance with reference to standard practices, with some leading in this field and developing better practices, better structures for formalising the activities of the profession are necessary. Presently, leaders in the forensic science continue setting standards by participation in national and international conferences and working groups, whilst followers are awaiting the publication of new standard practices, before their implementing these in the respective crime laboratories.

This fragmented system, in the absence of a uniform regulatory body for the profession, has led to the situation where certain forensic science experts' results have been scrutinised in recent times. An increasing number of unethical, unprofessional, and even immoral acts, impacting negatively

⁶ DesPortes BL “President’s message” 2018-02-19/24 *American Academy of Forensic Sciences (AAFS)*.

on the field, is becoming more noticeable over time and should be strongly condemned.^{7,8,9,10,11} However, because forensic investigations are historically well-known or publicised, mistakes appear to be increasing. These examples are of great interest to the public and provide sensational fodder for tabloid journalists. Roberts¹² mentions some of these criticisms and problems, many of which are pertinent for the purpose of this dissertation:

- *“Junk” science*:¹³ Forensic science is invalid (in the straightforward sense that it does not ‘work’: tests do not measure what they purport to measure, and results do not show what they purport to show).
- *Unvalidated and/or fallacious*:¹⁴ Forensic science techniques lack adequate validation, and in particular a proper statistical basis to support inferential generalisations.
- *Operationally deficient processing*:¹⁵ Forensic laboratories and practitioners lack adequate protocols and procedures to preserve physical samples from contamination or confounding degradation.
- *Methodologically unscientific*:¹⁶ Forensic science does not meet ‘scientific’ standards of objectivity, independence and impartiality/lack of bias, with particular susceptibility to ‘confirmation bias’ in reported findings.
- *Human fallibility*. Forensic scientists and expert witnesses make mistakes.

⁷ Farzan AN “Approximately 2,000 closed cases could be reopened due to BSO crime lab flaws Friday” 2016-09-30 *New Times, Broward, Palm Beach*.

⁸ Moxley RS “Orange County’s crime lab accused of doctoring DNA analysis in murder cases Tuesday” 2016-09-27 *Orange County Weekly*.

⁹ Augenstein S “Controversy at NY State Police lab results in lawsuit, call for outside investigation” 2016-02-22 2016 *New York Times*.

¹⁰ Allocca S “Disgraced lab analyst was high almost daily for 8 years” 2015-05-06 *Boston Herald*.

¹¹ Burke M “Misconduct scandal hits UK forensics lab” 2017-11-30 *Chemistry world*.

¹² Roberts P “Paradigms of forensic science and legal process: a critical diagnosis” 2015 *Philos Trans R Soc Lond B Biol Sci Aug 5 370(1674):1-11*.

¹³ Huber PW “*Galileo’s revenge: junk science in the courtroom*” (New York Basic Books 1991). Also, Giannelli PC “Junk science: the criminal cases” 1993 *J Crim Law Criminol* 84:105–128. Also, Bernstein DE “Junk science in the United States and the commonwealth” 1996 *Yale J Int Law* 21:123–182.

¹⁴ Giannelli PC “Forensic Science: Daubert’s Failure” Faculty Publications. School of law Case Western Reserve University. https://scholarlycommons.law.case.edu/faculty_publications/2006 (Date of use: 1 February 2020).

¹⁵ National Academic Press “Strengthening Forensic Science in the United States: A Path Forward” 2009. <https://www.ncjrs.gov/pdffiles1/nij/grants/228091.pdf> (Date of use: 1 February 2020).

¹⁶ Risinger DM *et al.* “The Daubert/Kumho implications of observer effects in forensic science: hidden problems of expectation and suggestion” 2002 *Calif Law Rev* 90: 1–56.

- *Charlatanism*: Experts are corrupt or incompetent fakers.
- *Overreaching*: Genuine experts stray beyond the bounds of their legitimate expertise in providing forensic opinions.
- *Lawyer ignorance/deliberate manipulation*: Lawyers and courts do not understand science properly, and consequently mishandle it and/or abuse it for their own strategic ends.
- *Communication failures*: Experts are incapable of expressing themselves (orally or in writing) in a manner comprehensible to non-specialists.
- *Lax ('liberal') admissibility standards*:¹⁷ Courts too readily admit questionable scientific evidence at trial, thus exposing fact-finders to exaggerated risks of adjudicative error.
- *Excessively demanding ('conservative') admissibility standards*: Courts too readily exclude novel or unconventional expert opinions, thus depriving fact-finders of information relevant to their decision-making.
- *Testimonial silencing*:¹⁸ Trial procedures for eliciting oral testimony prevent expert witnesses from communicating their evidence in their own language and on their own terms.
- *Adversarial deficit*: There is inadequate scientific support for the defence throughout the pre-trial and/or trial process.
- *Manufactured disagreement*: Adversarial trial procedures accentuate minor discrepancies between expert opinions, while obscuring substantial agreement.
- *Number-blindness*:¹⁹ In particular, laypeople do not understand the probabilistic or statistical basis of scientific evidence, producing localised versions of the following:
 - Juries do not understand scientific evidence, and too easily defer to expert testimony; or
 - Juries do not understand scientific evidence and, consequently, fail to credit expert testimony with the probative value it truly merits.

¹⁷ Robert R and Stockdale M "Forensic Science Evidence and Expert Witness Testimony: Reliability through Reform?" (Edward Elgar Publishers 2018).

¹⁸ Seckinger JH "Presenting Expert Testimony" 1991-1992 15 Am J Trial Advoc 215.
https://scholarship.law.nd.edu/law_faculty_scholarship/12 (Date of use: 1 February 2020).

¹⁹ Schneps L and Colmez C *Math on trial: how numbers get used and abused in the courtroom* (New York Basic Books 2013). Also, Hawkins P and Hawkins A "Lawyers' probability misconceptions and the implications for legal education" 1998 *Legal Stud* 18:316–335.

- *Two antithetical cultures*: Law and science are methodologically incompatible or “a troubled marriage of opposites”.²⁰

These are not new problems, however, as research conducted nearly three decades ago show,²¹ but scant attention was provided to these issues. Fortunately, as a result of political inquiries into the state of the forensic profession, four recent reports in both the United States and United Kingdom highlight some of the problems.

The first report, “*Strengthening Forensic Science in the United States: A path forward*”, was published by the National Academies of Science, Engineering, and Medicine in August 2009.²² The report followed after Congress in August 2005 directed the National Academy of Sciences (NAS) to undertake a study on the state of forensic science in the United States. By September 2006, a panel of 52 scientists, academics and other relevant experts had been assembled and started work that led to the 2009 report. The committee made it clear in the report that change and advancements, both systemic and scientific, are urgently required in a number of forensic science disciplines to ensure the reliability of the disciplines, establish enforceable standards, and promote best practices and their consistent application. It was an outcry for forensic science reform. This call was also echoed by academic and professional commentators.²³ The impact of the NAS report will

²⁰ Roberts *Paradigms* 2015. Also, Wonder AYK “Science and law, a marriage of opposites” 1989 *J Forensic Sci Soc* 29:75–76. Also, Haack S “Irreconcilable differences? The troubled marriage of science and law” 2009 *Law Contemp Probl* 72 1–23. Also, Brown S and Willis S “Complexity in forensic science” 2009 *For Sci Policy Manage* 1:192–198.

²¹ Roberts P and Willmore C “The role of forensic science evidence in criminal proceedings” 1993 *RCCJ Research Study No 11 HMSO*. Also, Roberts P “Science in the criminal process” 1994 *Oxford J Legal Stud* 14:469–506. Also, Roberts P “Forensic science evidence after Runciman” 1994 *Crim Law Rev* 780–792.

²² Committee on Identifying the Needs of the Forensic Sciences Community, National Research Council National Academics of Science, Engineering, and Medicine (NAS) Report 2009, “*Strengthening Forensic Science in the United States: A path forward*” August 2009. <https://www.ncjrs.gov/pdffiles1/nij/grants/228091.pdf> (Date of use: 18 July 2018).

²³ Cooley CM “Nurturing Forensic Science: How Appropriate Funding and Government Oversight Can Further Strengthen the Forensic Science Community” 2011 *Tex Wesleyan Law Rev* 17:441; Cooley 62:419–32. Also, Giannelli PC “Wrongful Convictions and Forensic Science: The Need to Regulate Crime Labs” 2007 (86) *NC Law Rev* 163:208–213, 217–219 Also, Moriarty JC and Saks MJ “Forensic science: grand goals, tragic flaws, and judicial gatekeeping” 2005 *Judges’ Journal* 44(4):16-33. Also, Plummer CM and Syed IJ “Shifted Science revisited: Percolation delays and the persistence of wrongful convictions based on outdated science” 2016 (64) *Clev St Law Rev* 483.

be examined in more detail in chapters five, six, seven and eight of this dissertation, specifically with regard to each of the forensic science disciplines addressed in those chapters. The second report, published in the United Kingdom in December 2014, titled “*The Home Office’s oversight of forensic services*”²⁴ by the National Audit Office (NAO), cautioned that the forensic science profession was under threat because police were increasingly relying on unregulated experts to examine samples from suspects and crime scenes. The report was a result of an inquiry by the House of Commons Science and Technology Committee in 2013, who concluded that major crimes would go unsolved unless the Government invests more in forensic science.²⁵ One key point was the lack of an official strategy to ensure that the forensic science ‘market’ was in good health, both in the short and long-term.²⁶ The third report appeared in 2015, when the UK’s Government Chief Scientific Adviser to HM Government, Sir Mark Walport, submitted a report, “*Forensic science and beyond: authenticity, provenance and assurance*”, which included reported case studies.²⁷ The report explored different ways in which analytical scientific tools, in combination with approaches and skills of the forensic scientist, may be used to reap the rewards of these benefits. The approach was to advise government regarding three domains of interest for the future of the forensic profession. They are:

- The identification of emerging technology and advice on how government can derive the greatest benefit for the economy, policymaking and delivery of government services;
- The provision of evidence supporting the development of government policy; and
- Support for national resilience and security.

²⁴ National Audit Office (NAO) “The Home Office’s oversight of forensic services” December 2014. <https://www.nao.org.uk/wp-content/uploads/2015/01/The-Home-Office's-oversight-of-forensic-services.pdf> (Date of use: 19 July 2018).

²⁵ Parliament in the United Kingdom “Science and Technology Committee - Second Report Forensic Science” 17 July 2013 www.parliament.uk. <https://publications.parliament.uk/pa/cm201314/cmselect/cmsctech/610/61002.htm> (Date of use: 19 July 2018).

²⁶ Forensic Science, House of Commons Science and Technology Committee, *Second Report of Session 2012/13 HC 610 July 2013*.

²⁷ Government Office for Science: The Government Chief Scientific Adviser's annual report, 2015-12-17.

The purpose of the report was not to criticise forensic science but to make recommendations that would lead to advancements in the profession. In March 2016, the Home Office published its “*Forensic Science Strategy*” to address some concerns from the National Audit Office report.²⁸ As part of this new strategy, the Government stated its intention to give the Forensic Science regulator statutory powers. However, to date no legislation has been promulgated to provide for such powers and authority.

In the same year, six years after the NAS report, the fourth report was published in the United States. In 2015, President Obama requested guidance from the President’s Council of Advisors on Science and Technology (PCAST) on whether there were additional scientific steps that may be considered in addition to those already taken by the Administration in order to improve the state of the forensic profession. This report appeared in the aftermath of the highly critical 2009 National Research Council report on the state of the forensic sciences, which would assist in improving the validity of forensic evidence used in the United States legal system.²⁹ In September 2016, the PCAST released a report, titled “*Forensic Science in Criminal Courts: Ensuring Scientific Validity of Feature Comparison Methods*”.³⁰ In the course of their one-year study, PCAST compiled and reviewed a set of more than 2 000 papers from various sources, educated itself on factual matters relating to the interaction between science and the law, and obtained input from judges, prosecutors, defence attorneys, forensic scientists and practitioners, academic researchers, criminal-justice-reform advocates, and representatives of Federal agencies.

²⁸ Home Office “Forensic Science Strategy: A national approach to forensic science delivery in the criminal justice system” March 2016.
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/506652/54493_Cm_9217_Forensic_Science_Strategy_Accessible.pdf (Date of use: 21 July 2018).

²⁹ Lander E et al. “PCAST Releases Report on Forensic Science in Criminal Courts” 2016-09-20 *The White House*. <https://obamawhitehouse.archives.gov/blog/2016/09/20/pcast-releases-report-forensic-science-criminal-courts> (Date of use: 21 July 2018).

³⁰ President’s Council of Advisors on Science and Technology (PCAST) “Forensic Science in Criminal Courts: Ensuring Scientific Validity of Feature Comparison Methods” 2016-09-20.
https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/PCAST/pcast_forensic_science_report_final.pdf (Date of use: 29 December 2019).

This report re-emphasised the role of scientific validity within the legal system; explained the criteria by which the scientific validity of forensic methods can be judged; applied those criteria to the forensic feature-comparison methods mentioned above; and offered recommendations on Federal actions that could be taken to strengthen forensic science and promote its rigorous use in the courtroom. The effect of the PCAST report on forensic disciplines will be discussed in more detail in chapters five, six, seven and eight of this dissertation.

The discussion above sketches the context of the research problem by reference to the current state of forensic science knowledge in the United States and the United Kingdom and highlights some of the challenges faced by the profession in general. It also alludes to the need for an interdisciplinary literature-based research study between forensic law and science to determine their integrated relationship.

This study will explore how forensic science has assisted adjudication and legal development in the field; how the law, in the form of legal judgments, has challenged the science, and how forensic disciplines responded to these challenges and reformed in response to criticism from key stakeholder reports, such as the NAS, NAO and PCAST reports. Most of the responses were in the form of research efforts to strengthen the “science” in forensic science that led to a wealth of information that crime laboratories currently are struggling to comprehend and absorb.

Knowledge production within the field of forensic science research has accelerated rapidly, leaving the forensic science field somewhat fragmented as a result. As mentioned by PCAST, accessing collective research in a particular research area poses a problem, making it difficult to stay abreast of new developments in the field. This is the reason why a literature review of forensic disciplines as a research method is more critically necessary and relevant than ever before.³¹ The literature review will address research questions that are not always possible in a single study. It will also provide an overview of areas in which the research is essentially different and interdisciplinary.

³¹ Snyder H “Literature review as a research methodology: An overview and guidelines” 2019 *J of Business research* 104:333-339.

The rationale for the study is furthermore strengthened by the need to:

- synthesise research findings in the different fields that will be explored in this study, and to
- view the evidence from a meta-level with the objective to uncover areas where more research is required, the latter an essential component of creating theoretical frameworks and building conceptual models.

This study will avoid a mistake made by PCAST, who followed a traditional systematic literature review that lacked thoroughness and whose report referred to authors whose research was premised on flawed assumptions, as will be pointed out in this study. Although the authors of the PCAST report followed a valid methodology, their contributions were constrained due to narrow perceptions shaped by only five years' of literature review. This study will take the reader back to the foundation of forensic disciplines, the challenges faced and successes achieved between the two prominent interdisciplinary domains of law and science.

The focus of the study is the United States. This choice is based on two main considerations, firstly that a comprehensive, interdisciplinary study of this nature has not yet been undertaken in the United States, and secondly, that the author of this thesis is part of a leading team of research professors in the field of forensic and investigative science, at West Virginia University, an R1-research intensive university in the United States.

1.3 Objective of the dissertation

Against the background of the research problem outlined above, the objective of this research dissertation is to conduct a qualitative literature review of the field of forensic science; to identify gaps in the knowledge of forensic science and its integration in the criminal justice system. The literature review will provide researchers within the field of forensic science with suggested research topics requiring further examination and research. The United States, as stated above, will provide the main context in which the above issues will be interrogated, for reasons outlined in

the problem statement above. In order to achieve its objective, the study will also critically analyse the historical development of, and evaluate the use of forensic science evidence in legal systems generally, including its role regarding the admissibility or inadmissibility of the evidence in the courtroom.

Findings and recommendations in the dissertation are not only informed by direct personal experience in the relevant disciplines, but the targeted focus is to suggest relevant recommendations aimed at improving the relationship between forensic science and law and the first-mentioned's role within the criminal justice system.

The reports referred to above alluded to the need for the forensic profession to either reform or revisit most of their disciplines in order to establish its rightful place as a professional and scientific entity.

In the final instance, international trends will be explored to determine weaknesses within certain forensic disciplines, to close the gaps by:

- clarifying forensic standards for the validity and reliability of forensic methods;
- evaluating selected forensic methods to determine whether they have been scientifically established to be valid and reliable; and
- assessing how the criminal law of evidence is applied in the courtroom, by referring to Daubert failures, as emphasised in law reviews and judgments, including its impact in other jurisdictions where the Daubert standard or parts of it the standard are applied.

With regard to the permissibility or admissibility of evidence based on, or derived from scientific practices, legislative changes may be required to better define when scientific or technical practices may and ought to be admissible in criminal hearings. It is axiomatic that every legal system should strive to provide the best, the fairest, the clearest and the most optimal context for judges and juries to determine the "truth" in an attempt to determine the rights and obligations of the parties and / or the need for a legal remedy or punishment. This will only be achieved when both forensic science

and the law are in agreement and have a clear grasp of the other discipline's language, terminology and limitations of applied methodology.³²

1.4 Research methodology

In this study, a narrative literature review approach will be followed. This approach is designed for topics conceptualised differently and studied by a variety of researchers within diverse disciplines, which may hinder a full systematic review process.³³ The meta-narrative review approach highlights the contrasting and complementary ways in which researchers have studied the same or similar topics in the relevant interdisciplinary areas. Hence, this dissertation will review research findings within selected disciplines in forensic science and will track their progress over time, as well as how the findings have developed across research traditions.³⁴ This approach will provide a better understanding of complex areas.³⁵

Interdisciplinary themes and different types of studies, where relevant and appropriate, will be included in order to assist with a transparent and well-developed research strategy that will enable the reader (legal practitioners and forensic scientists) to assess whether the arguments relating to the forensic evidence in the court judgments that will be referred to, were justifiable and reasonable, both from a methodological perspective and a conceptual one. The semi-systematic review makes it possible to map research conducted within various disciplines, to synthesise the state of current knowledge, and to create an agenda for further research that would follow on an already established foundation of discoveries. This methodology is best suited for complex topics, such as the topic of this dissertation, which is underpinned by the ostensible "disconnect" between law and science (as a result of factors mentioned in the problem statement). Since a comprehensive study of this kind has not yet been conducted between various disciplines interlinked with law, the author of this dissertation is of the opinion that such study is long overdue. For the review, four research

³² Moenssens AA "Admissibility of Scientific Evidence - An Alternative to the Frye Rule" 1984 *William & Mary Law Rev* 25(4):545-575.

³³ Wong G, *et al.* "RAMESES publication standards: Meta-narrative reviews" 2013 *BMC Medicine* 11:20.

³⁴ Snyder H *Literature review* 2019 (335).

³⁵ Wong G "Meta-narrative" 2013.

phases will be adopted, namely: (1) design; (2) conduct; (3) analysis; (4) and structuring, followed by the review writing.³⁶

In the design phase, the purpose of physical evidence and those who analysed it will be reviewed (admissibility of evidence and expert testimony). This will be followed by reviewing the disciplines within forensic science that attract the most attention within the larger legal and science community; their contribution to the science and how the science was challenged in legal proceedings. Also in the design phase, the potential audience will be selected, as well as what the thorny questions are that should be answered. In the conduct phase, a wide variety of resources including scholarly publications, text books, court judgments, official reports, laws and regulation, as well as historical events will be researched, whether in digital or written form. In the analysis phase, material relevant to the development of any of the selected topics will be critically examined. Relevancy will be determined by what the methodology was, or is being used, in past and current practices within those forensic disciplines. In the final stage, a well-defined structure is proposed on the writing of the review.

1.5 Structure of the thesis

As stated above, this study aims to evaluate the state of current forensic science knowledge in the United States. This process commences with plotting the evolutionary progress of the various disciplines within forensic science and how these found application within the criminal justice system. Issues that will be addressed are the question of what constitutes scientific validity, followed by a critical consideration of the development of legislation surrounding forensic evidence admissibility and expert testimony. This will be followed by an investigation of the language and terminology used to describe scientific methods based on historical development, its application within forensic science contributing to the law, and challenges faced. The study will also consider the impact of human factors relevant to decision-making from the crime scene to testimony. The study concludes with gaps identified within forensic disciplines and their impact on the criminal justice system, which should be explored in future research activities, as well as recommendations

³⁶ Snyder H *Literature review* 2019 (336).

of system models that will strengthen forensic science as a supporting entity within the justice system.

This study consists of nine chapters, which are structured as follows:

Chapter one (Introduction) presents a general introduction to the study. It addresses the contextual background to the research problem, the problem statement and rationale for the study. It also discusses the objectives, research methodology and structure.

Chapter two (Integration of science into forensic science) provides an overview of the concepts associated with the term forensic science. It reflects upon the scientific method in the context of forensic science, hypothesis testing and principles relevant to the interpretation of forensic evidence.

Chapter three (Legal aspects on expert testimony and evidence admissibility) compares legal aspects surrounding evidence admissibility and expert testimony in selected jurisdictions, notably the United States of America, United Kingdom, South Africa, and Australia.

Chapter four (Early scientific discoveries) studies early forensic science discoveries and the application of observation and research to formalise scientific methods within the scientific community.

Chapter five (Controlled substances) explores the specialisation of controlled substances through early legislative attempts following addiction; the methodology developed to identify controlled substances; legal challenges pertaining to scientific validity; external entities that influenced the credibility of the discipline, as well as future aspects within forensic drug chemistry.

Chapter six (Biology/deoxyribonucleic acid (DNA)) discusses the specialisation of biological evidence; scientific developments of forensic serology; the dynamic change in forensic biology; legal challenges relating to scientific validity in this context, concluding with a discussion of external entities that played a role in the credibility of DNA evidence; DNA mixtures, and future developments within forensic biology.

Chapter seven (Fingerprint evidence) focuses on the specialisation of fingerprints as impression evidence; early scientific discoveries on dermatoglyphics and scientific methodology; the physical and chemical development of latent fingerprints; standardisation and automation; legal challenges

relating to the scientific validity in this context, followed by an examination of the role of external entities with regard to the credibility, of and future developments within fingerprint identification. Chapter eight (Firearm and toolmark evidence) critically evaluates the specialisation of firearms and toolmarks as impression evidence; developments of firearms and toolmark as a scientific method; fundamentals of comparison' computerised imaging and databases; standardisation; statistical foundations; legal challenges relating to the scientific validity of this type of evidence, concluding with the role of, external entities on the credibility of and future developments with regard to firearms and toolmarks.

Chapter nine (Conclusion and recommendations) consists of a consolidation of all the key findings and specific recommendations, including those relating to language and terminology to be communicated by forensic experts, as well as recommendations on the establishment of business models to oversee the quality and value of forensic science and the law.

CHAPTER 2 Integration of science into forensic science

2.1 Introduction

Forensic Science, like many other professions, has a long-standing history of discovery and development. It is more than just a science: it is known as an integrated science with the greater effort of an investigation. When faced with novel forensic scientific complexities, it is often meaningful to reflect back on the historical development of science and discoveries made, before attempting to solve current or future problems. A logical starting point for this study is to explore the term "forensic science", including the foundational concepts and principles that constitute scientific methods and how these are applied today.

2.2 Concept "forensic science"

2.2.1 "Forensics"

The noun "forensics" refers to the art of debate, deriving from the Latin word "*forum*", e.g. the court as the place to debate. The Merriam Webster Dictionary³⁷ describes the adjective "forensic" as:

- belonging to, used in, or suitable to courts of judicature or to public discussion and debate a lawyer's forensic skills
- argumentative, rhetorical forensic eloquence
- relating to or dealing with the application of scientific knowledge to legal problems, forensic medicine, forensic science, forensic pathologist, forensic experts.

The adjective "forensic" is designated to connect with a public debate or more specifically, a court of law.

2.2.2 "Science"

It is the "science" component of "forensic science" that causes some confusion in modern society. The lay person believes science offers hard facts, definite conclusions, and uncompromised

³⁷ Merriam Webster: On-Line Dictionary "Forensic" https://www.merriam-webster.com/dictionary/Forensics?utm_campaign=sd&utm_medium=serp&utm_source=jsonld
(Date of use: 3 October 2018).

objectivity, and they do not understand the real reason for the existence of science. Judges and juries implicitly accept that science possesses a measure of legitimacy and credibility before it is deliberated in court. The science portrayed in the courtroom should be credible in order to deserve the trust it enjoys with the public, legal professionals and juries. When the scientific validity is questioned, the trust will dissipate and the scientific method should be revised.³⁸

This study will examine both the components of “*forensic*” and “*science*” in the literature review. In the “*forensic*” component, this study will analyse the role and admissibility of the expert witness in various jurisdictions globally. With regard to the “*science*” part, the focus will turn to the role and impact of the relevant forensic disciplines on the scientific method and how the law challenged the science in an open arena.

2.3 The scientific method in the context of forensic science

The essence of science is the scientific method.³⁹ Sir Francis Bacon was a lawyer and the Lord Chancellor of England under the reign of King James I. His *magnum opus*, titled, *Novum Organum*,⁴⁰ describes his first theory of the scientific method. According to Bacon, the scientific method, is a process of examining the natural world, and discovering important truths about it. He stated that scientists should be impartial observers without any preconceptions that might cause error in the scientific record. With continuous observations, patterns will emerge, giving rise to truths about nature. Science is hence a method of investigating, understanding and describing the physical universe. This concept is reflected in forensic investigations, such as forensic chemistry, forensic biology and pattern featured evidence (fingerprints and firearms), which will be discussed in chapters five, six, seven and eight respectively.

³⁸ Pyrek KM *Pioneers in Forensic Science: Innovations and Issues in Practice* (CRC Press 2018). From the paper of Koppl R “*How to improve Forensic Science*” 2005. <https://econwpa.ub.uni-muenchen.de/econ-wp/le/papers/0503/0503001.pdf> (Date of use: 3 October 2018).

³⁹ *Daubert v. Merrell Dow Pharmaceuticals Inc.* 509 U.S. 579, 593 (1993). “Science is not an encyclopedic body of knowledge about the universe. Instead, it represents a process for proposing and refining theoretical explanations about the world that are subject to further testing and refinement” (emphasis in original).

⁴⁰ Bacon F “*Novum Organum*” Original from 1891, (Joseph Devey J, Collier PF and Son (eds), New York, 1922). https://www.google.com/books/edition/Novum_Organum/Xc9xDgHgvaYC?hl=en&qbpv=1&printsec=frontcover (Date of use: 3 October 2018).

It is fundamentally impossible to observe nature without some form of reasoning for the selection of what to observe and not to observe. Since the time of Aristotle, reasoning based on observations has been important to scientific practice.^{41,42} The 20th century marks the period during which logical empiricists transformed philosophical thinking about observation in more detail. The implication of a long standing distinction between observation and experimentation was initially ignored in the first transformation process.⁴³ A number of philosophers and philosophically-minded scientists, historians, and sociologists of science gradually began considering the distinction between observation and experimentation.⁴⁴ Over time, scientists established two general rules of reasoning, the first described as “inductive reasoning”, which holds that arguments are viewed as strong enough when, if the evidence were to be true, then it would be unlikely that the conclusion is false. In other words, repeating patterns are identified and the pattern data are used (theorising from the definite to the natural). Put differently, in inductive reasoning, the conclusion is reached by generalising or extrapolating from specific cases to general rules. The second is termed “deductive reasoning” in terms of which arguments are deductively valid, involving a process of *reasoning*⁴⁵ from one or more *statements*⁴⁶ (premises) to reach a *logically*⁴⁷ certain.⁴⁸ Regardless of the reasoning, the observations made and experimental work that is done, constitute the scientific method.

The scientific method is the method used to confirm scientific knowledge and makes it reliable with the highest degree of scientific certainty possible, with the *caveat* that a 100% certainty in science

⁴¹ Aristotle (a) *Generation of Animals in Complete Works of Aristotle* (Princeton University Press Vol 1 J Barnes ed 1995) 774–993.

⁴² Aristotle (b) *History of Animals in Complete Works of Aristotle* (Princeton University Press Vol 1 J Barnes ed 1995) 1111–1228.

⁴³ Stanford Encyclopedia of Philosophy “*Theory and Observation in Science*” First published 2009-01-06; substantive revision 2017-03-28. <https://plato.stanford.edu/entries/science-theory-observation/> (Date of use: 5 January 2020).

⁴⁴ Robert Boyle (1661), John Herschell (1830), Bruno Latour and Steve Woolgar (1979), Ian Hacking (1983), Harry Collins (1985) Allan Franklin (1986), Peter Galison (1987), Jim Bogen and Jim Woodward (1988), and Hans-Jörg Rheinberger (1997).

⁴⁵ Merriam Webster (*Reasoning*-the drawing of inferences or conclusions through the use of reason).

⁴⁶ Merriam Webster (*Statement*- a report of facts or opinions).

⁴⁷ Merriam Webster (*Logically*- relating to, involving, or being in accordance with logic).

⁴⁸ Internet Encyclopedia of Philosophy, “Deductive and Inductive arguments” <https://www.iep.utm.edu/ded-ind/> (Date of use: 4 October 2018).

is impossible. This, as referred to above, alludes to the notion of error and uncertainty within the scientific method.⁴⁹

The scientific method is a fundamental aspect of science whereby a hypothesis is developed based on observational experiences, and then tested through experimentation or other impartial methods to confirm or refute the hypothesis. Forensic science is no different as fundamental aspects of science led to the development or evolution of forensic science, grounded in observational experiences throughout time, continuously tested to confirm or refute formalised hypotheses.

2.4 The hypothesis and its testing

Sir Karl Popper, a philosopher from Vienna, postulated that all science begins with a prejudice, a theory or a hypothesis.⁵⁰ The scientific method should be initiated from presumed knowledge that will lead to self-questioning, whilst keeping an open mind to change in beliefs within a context of scientific thinking, based on three entities: using empirical evidence (empiricism); practicing logical reasoning (rationalism); and possessing a skeptical attitude (skepticism). This is normally followed by a series of experimental tests and collection of empirical data to either support or disprove the hypothesis. To classify an endeavor of forensic science as science, the initiating scientists should be able to state a hypothesis and discover a way to test the hypothesis.⁵¹ The scientist should use the scientific method as a framework for the testing. If truthfulness of a concept, idea or theory cannot be proven, the failure to prove that it is false would be more realistic.⁵² Popper refers to the act of disproving a concept, theory or hypothesis as “falsification”. A theory or hypothesis is falsifiable when at least one potential falsifier exists, or one statement conflicts with it logically. Popper uses the example of the hypothesis of “all swans are white”. When a thousand white swans are observed, one might believe that all swans are white, until one black swan appears. This will

⁴⁹ Nearing GS and Gupta HV “Information vs. Uncertainty as the Foundation for a Science of Environmental Modeling” 2017. <https://arxiv.org/ftp/arxiv/papers/1704/1704.07512.pdf> (Date of use 4 October 2018).

⁵⁰ Popper K *The logic of discovery* Routledge Classics 1959. <http://strangebeautiful.com/other-texts/popper-logic-scientific-discovery.pdf> (Date of use: 5 January 2020).

⁵¹ Popper K “Discovery” 1959.

⁵² Shea B “Karl Popper: Philosophy of Science” Internet Encyclopedia of Philosophy. <https://www.iep.utm.edu/pop-sci/> (Date of use: 19 August 2019).

modify the hypothesis to “99.9% of swans are white” similarly susceptible to rigorous test but immune to certain proof. The same principles may be applied to forensic science. For example, no two people have the same DNA, except for identical twins. Years of data collected around the world supports this hypothesis. If scientists should discover two non-related people with similar DNA, the hypothesis will need to be modified. The scientific method is not wrong or unreliable, the value of the evidence may change over time as more information becomes available. In short, intersubjective testability should allow for reproducible results between researchers and practitioners.

Popper’s account of scientific methodology did not always receive positive reviews.⁵³ One of his critics was Thomas Kuhn,⁵⁴ who argues that observation is significantly influenced by one’s previous theoretical beliefs. Kuhn asserts that observers looking at the same phenomena may report radically different observations based on their own theoretical beliefs, especially if these derive from very different paradigms. Kuhn’s theory is eminent in observations in feature pattern evidence, which will become apparent in the discussion of the literature review regarding human factors in forensic examinations in chapters seven and eight.

Popper’s account of basic sentences acknowledges this potential shortcoming that will cause problems in attempts to falsify theories. His solution depends on the ability of the overall scientific community to reach a consensus as to which statement counts as basic and could be used to formulate tests. However, advocates of different theories are unable to reach an agreement on what sentences count as basic. These disagreements will ultimately prevent theories from ever being falsified.⁵⁵

Other theories were also followed regarding the scientific methods. Not all forensic science disciplines were established or developed from known scientific concepts, since some were developed from feature pattern observations made by those who had knowledge or an interest in

⁵³ See Kuhn (1962), Salmon (1967), Lakatos (1970, 1980), Putnam (1974), Jeffrey (1975), Feyerabend (1975), Hacking (1983), and Howson and Urbach (1989).

⁵⁴ Internet Encyclopedia of Philosophy “Thomas S. Kuhn (1922—1996)” <https://www.iep.utm.edu/kuhn-ts/> (Date of use: 5 January 2020).

⁵⁵ Internet Encyclopedia of Philosophy *Popper* 1959.

the field, for example, whether it would be possible to determine if this tool (“A”) made that marking (“B”). Sir Ronald Aylmer Fisher, an English statistician and biologist who used mathematics to combine Mendelian genetics and natural selection, referred to this as the *null hypothesis*.⁵⁶ Since then, a number of statistical approaches followed the concept to perform discriminating and adequate testing, and repeatedly failed to disprove the null hypothesis. These statistical approaches added scientific value to forensic evidence and will be discussed in more detail in chapters five, six, seven and eight of this dissertation.

2.5 Forensic science principles

Robertson *et al.*⁵⁷ argues that scientific methods are rapidly become dated and therefore proposes how such evidence ought to be interpreted and incorporated into the court process. They refer to three traditional principles that are followed in forensic science when interpreting evidence. These principles are the following:

(1) The *Locard* Exchange Principle

“A perpetrator will either leave marks or traces on the crime scene, or carry traces from the crime scene. This is often misquoted as ‘every contact leaves a trace’ but was never claimed by Locard.”⁵⁸

Originally, this principle referred to latent prints, footwear impressions, fibers, broken glass, but over time, it has been developed to include pollen, touch DNA, etc. Although the principle assumes that

⁵⁶ Kruskal W “The significance of Fisher: A Review of R.A. Fisher: The life of a Scientist” 1980 *J Am Stat Ass* 75(372):1019-1030. The term "null hypothesis" has been much distorted. In its original sense it referred to some statement about the distribution of the sample point that would, when true, be seldom rejected. Aside from that requirement, it might evidence no nullness; for example, $0 = 17$ or $G = F3$ (where "0" denotes a parameter, and "G" and "F" cumulative distributions) might be abbreviated statements of null hypotheses. Many or most null hypotheses may be trivially re-expressed as equalities with zero on one side, $C - 17 = 0$ or $G - F3 = 0$, but that is not of great interest. What might be "called a strong null hypothesis, or a null null hypothesis, is a statement that some transformation of the sample point leaves its distribution unaltered; for example, a null null hypothesis in a several-sample problem might be that the samples are really from a common distribution so that permuting their names does not affect the joint distribution.

⁵⁷ Robertson B *et al.* *Interpreting Evidence: Evaluating Forensic Science in the Courtroom* (Wiley 2nd ed 2016).

⁵⁸ Encyclopedia.com “*Locard's Exchange Principle*” Updated 2019-11-24.
<https://www.encyclopedia.com/science/encyclopedias-almanacs-transcripts-and-maps/locards-exchange-principle> (Date of use: 5 January 2020).

a mutual transfer of “tracks” takes place when two objects or persons come into contact with one another, modern day technology presents scenarios in which perpetrators are identified without two objects or persons physically coming into contact with one another in order to transfer “tracks”, e.g. the example of electronic signals, such as (invisible) mobile phone signals, where the use of technology may assist in linking a perpetrator to the scene of an incident or a contact person.⁵⁹ Locard’s exchange principle combines the question of the identity of the original source of transferred material, and the activity that led to the transfer and modification during and after the transfer. Many experiments contributed to the principle of transfer under certain conditions within multiple forensic disciplines.⁶⁰ However, transfer and loss through time is universal and can either be transferred through legitimate contact or alleged contacts. The exact time transfer occurred is not always possible to determine, although some studies were conducted to determine whether an observation could result by chance only or by specified contact.⁶¹ Locard’s exchange principle provides reliable information about past events, with the highest uncertainty arising from the reality of the alleged circumstances.

(2) The Principle of Individuality

“Two objects may be indistinguishable but no two objects are identical”.⁶²

⁵⁹ Zinn R and Dintwe S *Forensic investigation: Legislative principles and investigative practice* (Juta & Co 2015) 46.

⁶⁰ Curran JM, Triggs CM, Buckleton JS, Walsh KAJ and Hicks T “Assessing transfer probabilities in a Bayesian interpretation of forensic glass evidence” 1998 *Sci Justice* 38(1):15–21. Also, Grieve MC “Back to the future – 40 years of fiber examinations in forensic science” 2000 *Sci Justice* 40(2):93–99. Also, Wiedermann A *et al.* “Probabilistic evidential assessment of gunshot residue particle evidence (Part I): likelihood ratio calculation and case pre-assessment using Bayesian networks” 2009 *For Sci Int* 191(1–3):24–35. Also, Carter JF *et al.* “The distribution of controlled drugs on banknotes via counting machines” 2003 *For Sci Int* 132:106–112. Also, McDermott SD and Willis SM “A survey of the evidential value of paint transfer evidence” 1997 *J Forensic Sci* 42(6):1012–1018. Also, Lowe A *et al.* “The propensity of individuals to deposit DNA and secondary transfer of low level DNA from individuals to inert surfaces” 2002 *For Sci Int* 129(1):25–34. Also, Wickenheiser RA “Trace DNA: a review, discussion of theory, and application of the transfer of trace quantities of DNA through skin contact” 2002 *J Forensic Sci* 47(3):442–450. Also, Phipps M and Petricevic S “The tendency of individuals to transfer DNA to handled items” 2007 *Forensic Sci Int* 168(2–3):162–168.

⁶¹ Stoney DA *Transfer Evidence: In the use of statistics in forensic science* (Chichester UK Ellis Horwood 1991) 107–138.

⁶² Wittgenstein *Tractatus* 1922. Wittgenstein’s original text says “Von zwei Dingen zu sagen, sie seien identisch, ist ein Unsinn, und von Einem zu sagen, es sei identisch mit sich selbst, sagt gar nichts” (Tractatus 5.5303). Translated as “Saying two things are identical is nonsense, and saying one thing is identical with yourself says nothing”.

This means that every object, artificial or natural, is unique, although they may appear similar or identical. Locard's Principle and the Principle of Individuality should be regarded as principles only, as they do not fall within any standard definition of a law of science.⁶³

(3) The Individualisation Principle

"If enough similarities are seen between two objects to exclude the possibility of coincidence, then those objects must have come from the same source".⁶⁴

This is the principle with the biggest impact on forensic science. It is followed in many comparative arguments where unknowns are compared to known samples of a known source, from handwritings to fingerprints. Scientists like Sir William Herchel, Dr. Henry Faulds, Sir Francis Galton, and Sir Edward Richard Hendry, realised a need for the necessity of identifying persons.⁶⁵ These scientists over time developed and contributed to ways of positively identifying individuals by means of their fingerprints. Similar discoveries were made by firearm experts such as Calvin Goddard, Major Julien S. Hatcher and others, who discovered ways of connecting firearms to cartridge casings left behind at fatal crime scenes.⁶⁶ As far as handwriting is concerned, Albert S. Osborn and others proved that the way a person writes can be traced back to that individual.⁶⁷ A number of chemists, microscopists, physicists and biologists continued the development of scientific methods relating to the identification of persons.⁶⁸ For decades, these practices of identification and individualisation were applied to physical evidence and successfully admitted in international courts of law. It was, and is still is, considered of great value in courts. It should be noted that demonstrating similarities and differences was initially performed without a clear understanding by the examiners of the scientific foundation underpinning it. As time progressed, courts became more aware of the forensic science methodology that should inform and ground

⁶³ Popper KR *Conjectures and Refutations: The Growth of Scientific Knowledge* (Routledge 1963).

⁶⁴ Robertson *Interpreting Evidence* 2016 (2).

⁶⁵ International Association of Identification (IAI) "*Fingerprint Sourcebook*" (National Institute of Justice NCJ Number 225320 July 2011).

⁶⁶ Hamby HE "The history of firearm and toolmark identification" 1999 *AFTE Journal 30th Anniversary Issue* 31(3):266-284.

⁶⁷ Osborn AS "*Questioned Documents*" (Rochester New York 1910).

https://duienforcers.wildapricot.org/resources/QuestionedDocuments_Osborn_LawyersCoopPub_Co_1910.pdf (Date of use: 5 January 2020).

⁶⁸ Kirk PL "The ontology of criminalistics" 1963 *J Crim Law Crim Police Sci* 54: 235–238.

such an exercise, leading to a greater awareness of, and subsequent requirement to explain basic scientific laws and principles, rather than stating facts, observations or methods.

Although the principle of individualisation is often seen as being identical to identification, the distinction between the two concepts is significant. Whereas identification is concerned with the identification of something or somebody belonging to a specific category, individualisation, discussed below, involves comparison. For example, a comparison is used to determine whether the print in dispute that was found at the scene of an incident is that of a known perpetrator whose fingerprints are on record following previous convictions. To ensure that evidential material collected during an investigation process allows for the positive linking of suspects to an incident, both identification and individualisation should satisfy the following requirements, namely uniqueness; individuality; invariability; reproducibility and classifiability.⁶⁹ Although identity is philosophically defined as unique, it is the individuality that is of greater concern. When an expert identifies an object, that object is assigned to a specific class, for example a plant species in botany or compounds in chemistry. It is also possible to identify striation marks on a cartridge, without referencing the firearm discharging it or a fingerprint on a substrate without referencing the source of the print. The identification of physical evidence is seldom contested. The use of the term identification is only a prelude used by the forensic expert to individualisation. The end goal for the forensic expert is to establish individuality. Kirk states in this regard that:

“Thus, the entire subject of criminalistics started with a nomenclature that was inconsistent with science at large, and the terminology has never been brought into line by making the critical distinction of the field as a separate science of individuality.”⁷⁰

The individualisation principle also has flaws, because the possibility of coincidence should always be included, preventing the categorical statements of “individualisation”. To make the statement more scientific, scientists have to use the theory of probability to investigate the possibility of coincidence. The mathematics behind the possibility of coincidence was neglected for many years in comparative techniques.⁷¹ Moreover, comparisons may also be influenced by the notion of

⁶⁹ Zinn and Dintwe *Forensic investigation* [65].

⁷⁰ Kirk “The ontogeny of criminalistics” 1963.

⁷¹ Diaconis P and Mosteller F “Methods for studying coincidences” 1989 *J Am Stat Ass* 84:853–861.

“similarity”; e.g., what is seen to be similar for one scientist may not be as similar for the next. In addition, how scientists quantify “enough similarities” is another consideration.

These principles discussed above, as well as the limitations of Bertillon’s system or the methods of Bertillonage,⁷² as they became known, prompted forensic scientists during the last century to find new improved systems that would satisfy scientific requirements in comparison and identification. The Frenchman Alphonse Bertillon, known as the founder of identification, developed a method of identification, known as anthropometry, based on the uniqueness of the human frame, and rigid physical characteristics, which are not susceptible to change. Unfortunately the method of anthropometry had flaws and were highlighted in the Will West case of 1903, when the two West brothers, despite indistinguishable anthropometric measurements, were found to have completely different fingerprints.⁷³ This case is the *locus classicus* marking the turning point in America’s criminal justice system from anthropometry to fingerprinting.

Turning to the present, these systems of comparison methods were also those that became the focus of the United States’ PCAST committee. One of the objectives of the PCAST committee was to improve methods to determine whether an evidentiary sample (e.g., from a crime scene) is associated with a potential “source” sample (e.g., suspect) or not, based on similar patterns, impressions, or other features in the sample and the source.⁷⁴ The committee ultimately recommended that the forensic disciplines to revisit their scientific methods and the science underpinning those methods. Before reviewing the discipline specific literature, it would be worthwhile to look at the framework to the scientific method and apply it to each discipline.

⁷² For a discussion of some of the limitations, see <https://criminocorpus.org/en/exhibitions/suspects-defendants-guilty/alphonse-bertillon-and-identification-persons-1880-1914/> (Date of use: 3 August 2018).

⁷³ IAI Fingerprint Sourcebook 2011. Also, Will West Case <https://82141360.weebly.com/will-west-case.html> (Date of use: 3 August 2018).

⁷⁴ PCAST Report 2016.

2.6 The scientific method

2.6.1 *Framework to the scientific method*

Approaches to any new discovery related to forensic evidence should follow an experimental hypothesis and tested scientific method within a context of scientific thinking. The second step should then be to apply a statistical framework where results are disseminated and published for scrutiny by the scientific community.

An applied science is a science where the foundational validity of the scientific method rests on basic scientific principles and laws of physics, chemistry, and biology, amongst others. When performing analytical work on physical evidence, practitioners should not only know all chemical, physical and biological properties of that evidence, but also understand how interpretation of the results can be conveyed to probabilities or likelihoods. It requires an in-depth understanding of science and statistics, skills that have been lacking for many years in forensic science crime laboratories.⁷⁵ Lilienfeld and Stolley⁷⁶ explain that evidence accumulates to a point where a causal hypothesis becomes highly probable, but not possible to quantify the degree of probability achieved by all the evidence for a specific hypothesis, at which point only the element of subjectivity remains. It is this element of subjectivity that causes controversy in forensic and other sciences, where two practitioners may interpret the evidence differently.

Analytical work and research are normally performed under controlled conditions, where variables can be changed one at a time. In reality, physical evidence is recovered after deposition without any knowledge of the conditions they were exposed to before discovery. Some of the challenges during physical evidence discovery may be overcome by the application of critical thinking regarding the evidential value of the physical evidence at the scene of an incident. The notion that not all physical evidence necessarily has value should be followed.

⁷⁵ PCAST *Report* 2016.

⁷⁶ Lilienfeld DE and Stolley PD *Foundations of Epidemiology* (Oxford University Press 1994) 267.

In the past, and even to date, examiners in some crime scene units are hired as crime scene specialists or technicians, often lacking scientific educational background.⁷⁷ Some of these examiners rely solely on internal training programs related to basic concepts of collection, preservation, and, packaging of the evidence. In some instances, these examiners have a limited understanding of the physical, chemical and biological properties of the evidence discovered. No scientific method, regardless of its capability, can ensure quality results when the physical evidence is not correctly collected or preserved. This lack of critical thinking may also be carried over to crime laboratories where evidence will be directed to the appropriate disciplines. After collection and preservation, the critical thinking process continues when decisions are made regarding the scientific method, how to apply empiricism, rationalism, and skepticism. A number of critical steps are required if the scientist wants to be successful in applying the scientific method in practice, some of which include the following:

- Statement of the problem
- Gather Information
 - o Including observations
- Formulate a hypothesis
- Test the hypothesis
 - o Perform an experiment
 - With validated methods
 - Appropriate controls
 - Proficient and competent personnel
 - Performed more than once
 - o Collect the data
 - o Record the data
- Analyse the data
- Interpret the data
- Draw conclusions
- Report the conclusions

⁷⁷ See some AAFS job postings of Police Crime Scene Specialist, or Forensic Technician.
<https://webdata.aafs.org/public/jobs/postings.aspx> (Date of use: 5 January 2020).

- Retest
 - o Often performed by peers (other scientists)

These steps were deduced from the work of an array of great scholars, one of which was Al-Haytham,⁷⁸ regarded as the architect of the scientific method.

2.6.2 *Publications of the scientific method*

In an attempt to bring order and clarity to the magnitude of published papers within the forensic science community, causing more confusion than aiding the scientific problem, the Forensic Science Commission in the United States adopted a document, titled “Views of the Commission Regarding Identifying and Evaluating Literature that Supports the Basic Principles of a Forensic Science Method or Forensic Science Discipline”, in March 2016.⁷⁹ This document lists criteria by which scientific literature and methods may be assessed for consistency against principles of scientific validity. Such compilations are vital to the forensic discipline, as well as to the judicial system, where it should play an integral role in admissibility and gatekeeping practices.

The document recommended the following strategy by way of pertinent questions when reviewing scientific literature for scientific validity, namely:

- Does the publication adhere to the guidelines stated in the Forensic Science Commission’s document, “Views of the Commission Regarding Identifying and Evaluating Literature that Supports the Basic Principles of a Forensic Science Method or Forensic Science Discipline”? Is the problem or hypothesis clearly stated?
- Is the scope of the article clearly stated as appropriate (article, case study, review, technical note, etc.)?
- Is the literature review current, thorough, and relevant to the problem being studied?
- Does this work fill a clear gap in the literature or is it confirmatory and/or incremental?

⁷⁸ Pomeroy R “*Ibn al-Haytham: The Muslim Scientist Who Birthed the Scientific Method*” 2014-03-24. http://www.realclearscience.com/blog/2014/03/the_muslim_scientist_who_birtherd_the_scientific_method.html (Date of use: 8 August 2018).

⁷⁹ National Commission of Forensic Science “Views of the commission regarding identifying and evaluating literature that supports the basic principles of a forensic science method or forensic science discipline” 2016-03-22. <https://www.justice.gov/ncfs/file/839716/download> (Date of use: 5 January 2020).

- Are the experimental procedures clear and complete such that the work could be easily reproduced?
- Are the experimental methods appropriate to the problem?
- Are the methods fully validated to the necessary level of rigor (fit for purpose)?
- Are the data analyses and statistical methodology appropriate for the problem, and explained clearly so it can be reproduced?
- Are the experimental results clearly and completely presented and discussed?
- Are omissions and limitations to the study discussed and explained?
- Are the results and conclusions reasonable and defensible, based on the work and the supporting literature?
- Are the citations and references complete and accurate?
- Are the references original (primary) and not secondary?
- Are funding sources and other potential sources of conflict of interest clearly stated?

With the document, clear guidelines are given for future researchers to follow and ensure their work is correct and contributes to the scientific method.

2.7 Conclusion

The forensic analysis of physical evidence did not evolve overnight and is far from ideal. The forensic science community generally believes that, through the development of technology, scientific methods have been carefully selected, tested, data assessed, and interpreted. It makes scientists in general feel confident in presenting that physical evidence in courts of law.⁸⁰

Naturally, scientists are not observers, but through discovery and by describing their observations, they become Baconian observers.⁸¹ Scientists should be rigorous, passionate, and honest about reporting scientific results and how they are obtained, but like any other profession, there will

⁸⁰ Van Asten AC “On the added value of forensic science and grand innovation challenges for the forensic community” 2014 *Sci and Justice Mar 54(2):*170-179.

⁸¹ Sir Francis Bacon (1561-1626), Attorney General and Lord Chancellor of England, took up Aristotelian ideas, arguing for an empirical, inductive approach, known as the scientific method, which is the foundation of modern scientific inquiry.

always be some outliers.⁸² When new and unexpected predictions are formulated relating to an existing theory, these need to be verified by experimentation, which could reveal new and useful information supporting the theory. Even if the experiment disproves the theory, it may be of assistance in the sense that it may lead to the discovery of previously unknown information that may, in time, prove useful for other purposes, possibly requiring an explanation by novel theories postulated in due course.⁸³

Science continuously changes and evolves, giving rise to new and, invariably, enhanced ways of understanding the universe. Some new discoveries will replace older methods and make them absolute, whereas others would still be used in foundational support of a newer enhanced method. These changes and enhancements are never a smooth process and may take time to implement in crime laboratories. However, the quality of forensic science today is no doubt far more advanced than practices in the early to mid-20th century, which would not have been accomplished without research and development. The developments relating to DNA is one significant example, DNA analysis enabled the exoneration of many who were incorrectly convicted and may have spent many years in prison, from convictions that were based on previously underdeveloped methods or methods with low discriminatory value.⁸⁴ As Winston Churchill once observed: “The truth is incontrovertible. Malice may attack it and ignorance may deride it, but in the end, there it is.”⁸⁵

One of the world’s prominent forensic scientists in the first half of the twentieth century, Luke May, dedicated his career to forensics in solving crimes and searching for the truth. Often referred to as “America’s Sherlock Holmes”, May operated a private forensic laboratory and investigated cases for both law enforcement and defendants. Near the end of his life, he received an award with an inscription that read:⁸⁶

⁸² Inman K and Rudin N Principles and Practices of criminalistics: the profession of forensic science (CRC Press 2001) 19.

⁸³ Inman *Criminalistics* 2001 [16].

⁸⁴ Inman *Criminalistics* 2001 [86].

⁸⁵ Guthrie G *1,600 Quotes & Pieces of Wisdom* (Universe Inc 2003) 64.

⁸⁶ Deputy Attorney General Rosenstein Delivers Remarks at the American Academy of Forensic Sciences (AAFS) Seattle, WA, 2018-02-21.

“Some seek truth for convenience; some for recognition; few have sought it so diligently for so many years to prove equally innocence or guilt.”

Luke May’s unbiased search for truth might be unusual in some professions, but not in forensic science and law. More often than not, the search for the truth is not easy. The forensic science of today remains founded on principles of hypothesis testing, scrupulous study design, meticulous data collection, and objective interpretation of experimental results and observations.⁸⁷

For those who sought the truth to equally prove innocence or guilt, an unbiased platform is needed to deliberate on discoveries made through experimental results, observations made, and opinions formed. That platform was created through legislation and rolled out in courthouses. This study will first explore the establishment of jurisdictional platforms where the need for qualified expert witnesses and the admissibility of evidence that they would be testifying on, are expressed, before the contribution of the forensic scientific methodology is covered. This will allow the reader to understand the purpose of forensic expert witnesses and the admissibility rules on evidence that they will be testifying on, ultimately assisting the court in finding the truth.

⁸⁷ Deputy Attorney General Rosenstein *Remarks* 2018.

CHAPTER 3 Legal aspects on expert testimony and evidence admissibility

3.1 Introduction

In this section, the description, purpose and value of evidence control and expert witnesses in legal proceedings generally will be discussed. It is important that all the role players in any legal proceeding know and understand the legislation underpinning the purpose and value of expert witnesses, limitations to their testimony, and, the value of the evidence on trial. Without well-defined litigation and law of evidence rules, the court system will be chaotic and fragmented. The rules should clearly define expert testimony and admissibility/inadmissibility of expert evidence in trials. Although there are many different legal systems globally, and different court structures, hierarchies, jurisdictions and levels (e.g. county, state, high court, federal, magistrate court etc.), the role of the expert witness should be a constant factor across these systems. The expert witness should be qualified as an expert by knowledge, skill, experience, training, and/or education to testify in the form of an opinion or otherwise stipulated by the relevant jurisdiction. Four basic criteria for expert testimony may be summarised in the following:⁸⁸

- the expert's scientific technical, or other specialised knowledge should help the trier of fact to understand the evidence and value thereof, or determine a fact in issue;
- the testimony is based on sufficient facts or data;
- the testimony is the product of reliable principles and methods; and
- the expert has reliably applied the principles and methods to the facts of the case.

The expert witness as an expert should assist the court, the larger community or any individual in solving an issue, because he/she possesses specialised knowledge of a specific topic or research field.⁸⁹ Stephen Breyer explains the need for expert witnesses as follows:

⁸⁸ Federal Rules of Evidence *Public Law 93-594, 2 January 1975 (88 STAT)*, [1926]. Last amended on 1 December, 2019.

⁸⁹ Meyer C *Expert witnessing explaining and understanding science* (Boca Raton Fla CRC Press 1999). Also, Kreiling KR "Scientific Evidence" 1990 *Arizona Law Rev* 32:915-983.

“Judges are not trained scientists. They inevitably lack the scientific training that might facilitate the evaluation of scientific claims or the evaluation of expert witnesses who make such claims.”⁹⁰

Expert witnesses possess knowledge and skills that the average person lacks.⁹¹ To understand the difference between an expert and a layman, one should be able to differentiate between an expert and a witness.⁹² The courts should clearly distinguish between the two. As discussed in the previous chapter, a perception exists that the general legal culture was and remains, to some extent, discordant with a scientific perspective. The term “*stare decisis*” refers to the legal doctrine that obligates courts to follow historical cases or precedents in making a decision, and decisions made in a higher court are binding on lower courts in all future cases where the facts are substantially similar. Appellate courts are often required to revisit possible errors by trial courts in a given case.⁹³ Faigman and Saks maintain that flawed evidence is often carried forward from one trial to another. They attribute the “failure” of forensic science in these cases to lawyers, who may not have had sufficient knowledge of basic methods of science and may have lacked the ability to appropriately frame an assessment of such claims.

In order to accurately describe the role of forensic evidence in law, it is necessary to take a step back in time and review the legal history on the inception of expert testimony and the admissibility of forensic evidence in law.

3.2 Legal aspects relating to forensic evidence prior to the 19th century

The first known forensic opinion provided by an expert was that of Anistius during the Roman Empire regarding the judicial death investigation of Julius Caesar (c. 100 – 44 BC).⁹⁴ Anistius was

⁹⁰ Breyer S “The interdependence of science and law” 1998 *Science* 537(280):25-26.

⁹¹ Meintjes-Van der Walt L Expert evidence in the criminal justice process (Purdue University Press 2001) 63-84.

⁹² Cappellino A “Lay Witness vs. Expert Witness Opinions: A Primer” The Expert Institute, 2016-12-27 <https://www.theexpertinstitute.com/lay-witness-vs-expert-witness-opinions-primer/> (Date of use: 6 June 2019).

⁹³ Faigman DL and Saks MJ “Failed Forensics: How forensic science lost its way and how it might yet find it” 2008 *Annual Rev Law Soc Sci* 4:149–171.

⁹⁴ Sheldon N “*The Earliest Recorded Autopsy in History Was Performed on This Roman Emperor*” History Collection, <https://historycollection.co/julius-caesar-complicit-death-re-examining-earliest-autopsy-history/> (Date of use: 6 June 2019).

of the opinion that only one of the twenty-four stab wounds that Caesar received was deadly, namely the one that penetrated Caesar's sternum. In the sixth century AD, emperor Justinian, also known as Justinian the Great and Eastern Roman emperor from 527 to 565 AD, recognised the special position of the expert witness when he declared that physicians were not ordinary witnesses, but rather persons who gave judgment (today better known as opinions), instead of testimony.⁹⁵

In 1209, Pope Innocent III of Italy appointed doctors to the court system to perform all autopsies where wounds were noticed on the deceased. Italy became the first country that recognised legal medicine as a field of specialty.⁹⁶

The early European court systems used expert opinions in two possible ways. One was to appoint various persons based on their experience to listen to expert opinion testimony (similar to the jury system). The second was to appoint persons based on their knowledge and skills with the objective that these persons would assist the court. The court had then the discretion to either accept or reject the testimony.⁹⁷

Prior to the 1700s, most known forensic evidence delivered in open arenas involved medical evidence in all cases involving violent crimes.⁹⁸ This appears from the classic Chinese work, "Instructions to Coroners" in 1205, the "Bamberg Code" in Germany in 1507, and "Ambrose Pare" (1510-1590) in France. England and continental European legal systems followed (and still follow) different approaches when investigating and prosecuting crimes. In contrast to continental Europe that followed a judge-led court system using torture as a form of punishment, England adopted a

⁹⁵ Hussey JM "Justinian I: Byzantine Emperor" *Encyclopaedia Britannica*, Last updated: 2019-11-10.

⁹⁶ Tilstone WJ *et al.* "Encyclopedia of Forensic Science" 2006 *An Encyclopedia of History Methods, and Techniques* ABC-CLIO.

⁹⁷ Hand L "Historical and practical considerations regarding expert testimony" *1901 Harvard Law Rev* 15:40. Refer to thus as follows - ... "there seem to have been two modes of using what expert knowledge there was: first, to select as jurymen such persons as were by experience specially fitted to know the class of facts which were before them, and second, to call to the aid of the court skilled persons whose opinion it might adopt or not as it pleased."

⁹⁸ Tilstone "Encyclopedia of Forensic Science" 2006.

determination of proof through a jury system (from an accusatory role to determination of guilt).⁹⁹ The English courts started accepting the evidence of experts around the middle of the fourteenth century in criminal matters and the sixteenth century in civil matters.¹⁰⁰ Two distinct roles that evidence played in courts were recognised at the time: the role that the experts adopted or were required to adopt in making their contribution to the criminal fact-finding process, and the represented changes in the substance of the evidence involving the increased complexity of specialist inferences. Experts were required to testify in different settings in the court and evidence was presented in different ways, depending on the court system in operation. In England, the first system was by the common law courts in relation to law of evidence in criminal hearings, and the second by the civilian High Court of Admiralty. In 1621 in the case of *Adams v Canon*,¹⁰¹ the opinion testimony of the experts was rejected on the ground that the evidence was lacking facts. Presiding officers in hearings had to base their decisions on facts of opinion, and facts had to be claimed and proved.

One year later, in 1622, it was determined that expert witness testimony could be delivered in a court of law related to the topic in question and that the evidence would be accepted if it could be supported by another expert skilled in the same trade.¹⁰²

In the early 1700s, specialists started to separate themselves into sub-categories of chemistry and biology and testified accordingly.¹⁰³ In 1827, new legislation was passed from which time defendants who refused to plead were deemed to be entering a plea of not guilty.¹⁰⁴ Coroner's juries were summoned to be in court due to their knowledge of the death of a person, and they subsequently acted as both witness and determiner of fact during these trials.¹⁰⁵

⁹⁹ Langbein JH *Torture and the Law of Proof: Europe and England in the Ancient Régime* (Chicago: University of Chicago Press 2006) 240.

¹⁰⁰ Milroy CM "A Brief History of the Expert Witness" 2017 *Dec Academic Forensic Pathology* 7(4):516–526.

¹⁰¹ *Adams v. Canon* (1621) Dyer 53b n.15.

¹⁰² Hand *Expert testimony* 1901 [45].

¹⁰³ Hand *Expert testimony* 1901 [45].

¹⁰⁴ Langbein JH *et al.* "History of the common law: the development of Anglo-American legal institutions" 2009 *New York: Wolters Kluwer Law & Business* 1141.

¹⁰⁵ Hunnissett R *The Medieval Coroner* (London: Cambridge University Press 1961).

By the end of the seventeenth century, the role of the judge as active participant in court during questioning of court initiated witnesses, changed to a more umpire orientated role. Lawyers took over the examination of witnesses, and developed the technique of cross-examination, establishing their right to argue points of law, and transforming the legal system into an adversarial system. At the time, the expert witnesses found the transition challenging, because they were used to be either part of the jury or acting as court advisors.¹⁰⁶ In other countries, such as Germany and some other European civil legal systems, the judiciary still played a more active and proactive role (inquisitorial system), compared to the adversarial approach then followed in most common law legal systems.

Both the common and civil law systems have specific advantages and disadvantages in criminal proceedings. Miscarriages of justice are not uncommon. In the inquisitorial system where the court or a part of the court is actively involved in investigating the facts of the case, judges tend to overly rely on the well-credentialed expert opinion, which may escape rigorous testing. On the other hand, in adversarial systems where the role of the court is primarily that of an impartial referee between the prosecution and the defence, defendants or accused may be misled by unskilled, overworked or unprepared attorneys to agree to a plea bargain or settlement without trial.¹⁰⁷ In the early adversarial system, the presiding officer would lead the expert witness and then allow the accused to cross-examine the witness.¹⁰⁸ The accused was also allowed to address the court after testimony, making a statement about the outcome of evidence against them.¹⁰⁹

It was Lord Mansfield who paved the way and laid the rules for expert opinion evidence that have since influenced common law jurisdictions. The first known court decision on the admissibility or inadmissibility of expert opinion is that in the case of *Folkes v Chadd* in 1782.¹¹⁰ Although not directly related to forensic evidence, the case dealt with expert opinion and the facts supporting the

¹⁰⁶ Golan T “*Laws of men and laws of nature: the history of scientific evidence expert testimony in England and America*” (Cambridge (MA): Harvard University Press 2004).

¹⁰⁷ Roberts “Paradigms of forensic science” 2015.

¹⁰⁸ Du Plessis JR “An inquisitorial system in practice – visits to German criminal courts” 1988 *South African Law J* 105:308.

¹⁰⁹ Du Plessis JR *Inquisitorial system* 1988 [307].

¹¹⁰ *Folkes v. Chadd* (1782) 3 Douglas 157, 99 ER 589.

opinion. Lord Mansfield referred to expert witnesses as men of science, and on the appeal for the admissibility of opinion from one of the “men of science”, he made the following observation:

“It is objected that Mr. Smeaton is going to speak not to facts, but to opinion. That opinion, however is deduced from facts which are not disputed – the situation of banks, the course of tides and of winds, and the shifting of sands. His opinion, deduced from all the facts is, that mathematically speaking, the bank may contribute to the mischief, but not sensibly. Mr. Smeaton understands the construction of harbours, the causes of their destruction and how remedied. In matters of science no other witnesses can be called. An instance frequently occurs in actions for unskill-fully navigating ships. The question depends on the evidence of those who understand such matters; and when such questions come before me, I always send for some of the brethren of the Trinity House. I cannot believe that where the question is whether a defect arises from natural or an artificial cause, the opinions of men of science are not to be received. Handwriting is proved every day by opinion, and for false evidence on such questions a man may be indicted for perjury. Many nice questions may arise as to forgery and as to the impression of seal, whether the impression was made from the seal itself or from an impression in wax. In such cases I cannot say that the opinion of seal-makers is not taken. I have myself received the opinion of Mr. Smeaton respecting wills, as a matter of science. The cause of the decay of the harbour is also a matter of science, and still more so, whether the removal of the bank can be beneficial. Of this, men such as Mr. Smeaton alone can judge. Therefore, we are of the opinion that his judgment, formed on facts was very proper evidence.”¹¹¹

The Courts of Chancery, known as the Chancery Division after 1873, one of three divisions of the High Court of Justice in England and Wales,¹¹² allowed for counsel and opposing counsel to make submissions to the presiding officer, the Chancellor. As a rule, no cross-examinations of expert witnesses were allowed, with limited exceptions.¹¹³

Prior to 1790, no legal term existed for expert testimony. Brief reports were made on the use of expert testimony in criminal trials. Opinions of well-known scientists, anthropologists or physicians

¹¹¹ Golan *Laws of men* 2004 [325].

¹¹² Dwyer DM “Expert evidence in the English civil courts 1550-1800” 2007 *The Journal of Legal History* 28(1)93-118:102; Anonymous 1902:374 - The practice which prevailed in the English Courts of Chancery until within the last fifty years, has been compared to that of the civil law of which Roman-Dutch law is a branch; Erasmus 1991:267 - The Court of Chancery administered equity in Lincoln’s Inn and the courts of common law administered law in Westminster Hall.

¹¹³ Anonymous 1902:374 - For many centuries the Court of Chancery decided cases upon affidavit evidence with occasional oral cross-examination.

were sometimes requested, which would count as testimony.¹¹⁴ The term “expert” first appeared in English legal writings in 1795, when the Irish barrister Capel Lofft wrote in his edition “*Gilbert’s Law of Evidence*” that:

“The proof from the Attestation of Persons on their Personal Knowledge, we may properly, with the French lawyers, call proof by Experts”.¹¹⁵

The word “expert” is not used in the English Law Reports as a local term until 1858, when it appeared in a few citations. In *R. v Esdaile and others*,¹¹⁶ Lord Campbell CJ stated the following:

“The proper way of putting the question is to ask the witness, as an ‘expert’, whether mines are convertible securities.”

The witness in this case had been called to show that the investment of money in immoveable property was not a legitimate part of the business of banking.

Two years later, in the 1860 Chancery court judgment in *Directors of the Stockton and Darlington Railway v John Brown* (a “lunatic”),¹¹⁷ counsel submitted that “[t]he court is not bound by the report of the expert.” In the case of *Lord Abinger vs. Ashton*,¹¹⁸ the Master of the Rolls, Sir George Jessel, indicated his distrust of expert witnesses and accused them of being biased to the side who called them. This was followed by the case of *Thorn vs Worthing Skating Rink*, where Sir Jessel commented that: “with respect to courts appointing their own experts, the courts first had to find an

¹¹⁴ Dwyer DM *Expert evidence* 2007 [102]. “The absence of a term does not necessarily mean that the concept was also absent. However, until the rules on expert opinion evidence developed in the second half of the eighteenth century, it seems probable that the different professions and disciplines were seen as presenting distinct types of specialist advice, rather than being specific examples of a general legal category which we now call experts.

¹¹⁵ Gilbert G *The Law of Evidence* (C Lofft Dublin 4th ed 1795). By “personal knowledge”, Lofft is referring to knowledge that the witness possesses, separate from what was seen or heard in the instant case. According to Leclerc, ‘Le Juge et l’Expert’, 54, expert was not used as a legal noun in France until the end of the eighteenth century. The word as an adjective was also used to refer to a person of practical skill rather than special knowledge until around the same time.

¹¹⁶ *R. v. Esdaile and others* (1858) 1 F. & F. 213, at 230, 175 ER 696, [705] [294]. The witness was called “to show that the investment of money in landed property was not a legitimate part of the business of banking”.

¹¹⁷ The English Reports: The English Reports: House of Lords (1677-1865), Volume 4.

¹¹⁸ *Abinger v. Ashton*, (1873) 17 LR Eq 358.

unbiased witness, which was very difficult”.¹¹⁹ This critique was echoed in the United States in 1859, in the case of *Winans vs. New York and Erie Railroad*, when Supreme Court Judge Griere stated that: “[...] experience has shown that opposite opinions of persons professing to be experts may be obtained to any amount”.¹²⁰

The use of an expert, based on the person's knowledge of firearms was allowed in the United States in 1876, when a Georgia State Court, permitted expert testimony from a person with expert knowledge of firearms, specifically concerning the amount of time that had lapsed since a firearm was last discharged.¹²¹ In 1879, a Minnesota State Court, utilized the services of a qualified gunsmith to examine a fatal bullet in conjunction with two suspect revolvers. The gunsmith's examination of the two revolvers revealed that one of the revolvers had actual rifling marks, whilst the other revolver only had false rifling marks at the muzzle. His examination of the two revolvers and his in-depth examination of the striation marks on the fatal projectile enabled him to testify that the projectile could not have been discharged from the revolver with rifling marks, but might have well been discharged from the other revolver.¹²² A similar case involving testimony concerning the time that lapsed since a firearm was last discharged, occurred in a Texas State Court in 1883. The court allowed an individual to provide expert testimony on the lapsed time since the evidence firearm was last discharged. His testimony was based on his examination of the fired wadding (paper patch), the percussion cap (a small metallic cup containing a primary explosive used to ignite the muzzle charge in muzzle-loading firearms), and the barrel of the firearm.

By the end of the 19th century, Simon Greenleaf stated in his US textbook on evidence that “there was no specific rule admitting opinions or inference when made by one class of persons – experts – and excluding them from when made by another class – layman; but there is a rule excluding them whenever they are superfluous and admitting them whenever they are not”.¹²³

¹¹⁹ *Thorn v. Worthing Skating Rink Co.*, (1876) 6 Ch D 415.

¹²⁰ *Winans v. New York & Erie R. Co.*, 21 How. 88 (1859).

¹²¹ FirearmsID.com http://www.firearmsid.com/a_historyoffirearmsid.htm (Date of use: 9 September 2018).

¹²² FirearmsID.com http://www.firearmsid.com/A_historyoffirearmsID.htm (Date of use: 9 September 2018).

¹²³ Opinion rule. In: *A treatise on the law of evidence by Simon Greenleaf* (Boston: Little Brown and Company 16th ed 1899) 440–441.

The next section will examine the relationship between forensic science and the law during the 20th and 21st centuries. During this period, forensic science disciplines became more specialised and courts in both civil and common law systems increasingly started to rely on their evidential value more frequently in both criminal and civil hearings.

The problems and challenges were not limited to one specific continent or jurisdiction. Establishing a set of rules for admitting expert evidence and determining the value of evidence was, and remains until today, a difficult task. The next section will have a closer look at these challenges as they arose in different jurisdictions respectively.

3.3 Legal aspects related to forensic evidence

In this chapter, four jurisdictions will be compared with regard to their respective approaches to expert evidence by courts. The first jurisdiction, the United States, is selected for its development of the field, following the landmark cases of *Fye* and *Daubert*, discussed in detail below. Reference is next made to the United Kingdom, whose legal history is an equally striking and influential one, followed by Australia, whose well-established approach to “special knowledge” merits discussion, and finally, South Africa, a jurisdiction that has drawn to a large extent from practices and approaches in the aforementioned jurisdictions.

3.3.1 United States of America

The rules of evidence were developed over several centuries and were based upon the rules from Anglo-American common law brought to the New World by early settlers. Their purpose was to be fair to both parties, disallowing the raising of allegations without a basis in provable fact. These rules, often criticised for constituting legal technicalities, remain an important part of the legal system for achieving a just result.

As early as 1553, when the United States’ legal institutions were still in their formative stages, it was judicially noted that:

“If matters arise in our law which concern other sciences or faculties, we commonly apply for the aid of that science or faculty which it concerns, which is an honorable and commendable thing in our law, for thereby it appears that we do not despise all other sciences but our own, but we approve of them, and encourage them as things worthy of commendation.”¹²⁴

It was during the 16th century, when jury and proof by witness trials (distinction between juror and witness) were developed, that the exclusionary rules were formulated,¹²⁵ which determined the competency of witnesses and admissibility of evidence. The original purposes were to guard the jury from being misled by the testimony and to keep the considerations of the jury within the issues of the pleadings. One of the exclusionary rules mentioned by Wigmore was the “opinion” rule, still applied in modern legislation, but not for expert witnesses:

“[A] witness testifying to his experience in regard to the matters in issue should testify to the “facts” observed and not to his own opinion or inference therefrom. After such testimony is produced, the trier of fact is deemed capable of making the inferences or framing the opinion”¹²⁶

It was that special skill or experience that was required to allow the witness in aiding the tribunal in arriving at conclusions from the fact. In the trial of *Dougherty v. Milliken*¹²⁷ the court stated that:

“[I]n the one instance the facts are to be stated by the experts and the conclusion is to be drawn by the jury; in the other, the expert states the facts and gives his conclusion in the form of an opinion which may be accepted or rejected by the jury.”

¹²⁴ Saunders J, in *Buckley v. Rice*, x Plowd. 125 (1554).

¹²⁵ Holdsworth WS “*A History of English Law*” Internet Archive 1926 [133-139]. See also, Thayer notes, Introduction. Thayer says: “Reasoning . . . the rational method of settling disputed questions is the modern substitute for certain formal and mechanical ‘trials,’ or tests, which flourished among our ancestors. . . . But now when we use the phrase ‘trial’ and ‘trial by jury’ we mean a rational ascertaining-of facts, and a rational ascertaining and application of rules. What was formerly ‘tried’ by the method of force or the mechanical following of form, is now tried by the method of reason.

¹²⁶ Wigmore JH *A treatise on the Anglo-American system of evidence in trials at common law: including the statutes and judicial decisions of all jurisdictions of the United States and Canada* (2nd ed Boston: Little Brown 1923).

¹²⁷ *Dougherty v. Milliken*, 163 N. Y. 527, 57 N. E. 757 (1900).

Wigmore¹²⁸ also defined the experts in terms of their ability to comprehend the nature of experiences falling within their perception and stated “[t]hat sort of capacity, which involves, not the organic powers, moral and mental, requisite for all testimony, nor yet the emotional power of unbiased observation and statement, but the skill to acquire accurate conceptions may be termed experiential capacity. The person possessing it is commonly termed Expert.”

As early as 1923 it was already impossible to describe all possible instances where expert testimony would be admissible. Wigmore¹²⁹ held that such an exercise would serve no purpose and would not help the jury. He then defined the evidence as “[a]ny knowable fact or group of facts, not a legal or logical principle, considered with a view to its being offered before a legal tribunal for the purpose of producing a persuasion, positive or negative, on the part of the tribunal, as to the truth of a proposition, not of law or of logic, on which the determination of the tribunal is to be asked.” He mentioned some examples where testimony had already been admitted, namely in the cases of medicine,¹³⁰ x-rays,¹³¹ electricity and electric lights,¹³² chemistry,¹³³ handwriting,¹³⁴ fingerprints,¹³⁵ and ballistics.¹³⁶

It was believed by some¹³⁷ that the expertise from patterned evidence analysis originated as a result of a national push in the early 20th century to professionalise police investigative techniques at a time when the United States was particularly drawn to science. Law enforcement borrowed

¹²⁸ Rosenthal LL “The development of the use of expert testimony” 1935 *Law and Contemporary Problems - Expert Testimony* 2(4):403-418.

¹²⁹ Wigmore, note 2 §1923.

¹³⁰ *Hickenbottom v. D. L. & W. R. R.*, 122 N. Y. 95, 25 N. E. 279 (1890); *Young v. Johnson*, 123 N.Y. 226, 25 N. E. 363 (1890); *Stouter v. Manhattan Ry. Co.*, 127 N. Y. 661, 27 N. E. 805 (1891); *Cross v. City of Syracuse*, 200 N. Y. 393, 94 N. E. 184 (1901).

¹³¹ *Marion v. Construction Co.*, 2x6 N. Y. 178, iio N. E. 444 (1915).

¹³² *Prickett v. Sulzberger & Sons CO.*, 57 Okla. 567, 157 Pac. 356 (1916).

¹³³ *San Marcos Oil Mill v. Soyars*, 265 S. W. 173 (Tex. Civ. App. 1924).

¹³⁴ *Sudlow v. Warshing*, 108 N. Y. 520, 15 N. E. 532 (1887); *People v. Molineux*, 168 N. Y. 264, 61 N. E. 286 (1901).

¹³⁵ *People v. Roach*, 215 N. Y. 592, 109 N. E. 618 (1915).

¹³⁶ *People v. Fisher*, 340 Ill. 2z6, 172 N. E. 743 (1930).

¹³⁷ Equal Justice Initiative “*Investigative Report Details Flaws in Forensic ‘Science’*” 2018-07-02.

terms from science, establishing crime “laboratories”, staffed by forensic “scientists”, who announced “theories” cloaked in their own specialised expressions. However, forensic “science” focused on inventing clever ways to solve cases and win convictions; it was never about forming theories and testing them according to basic scientific standards. They believed that by adopting the trappings of science, the forensic disciplines co-opted the authority of science, while abandoning its methods.¹³⁸ These discrepancies called for some form of acceptance of expert evidence based on sound knowledge and foundational science.

3.3.1.1 Birth of the “general acceptance” rule

Amid the swirl of new forensic techniques, the realisation dawned that there had to be a gatekeeping mechanism to filter out dishonest or underdeveloped practices. In 1923, the first significant change came in the United States in the case *Frye v. United States*.¹³⁹ James Alphonzo Frye appealed his conviction for second degree murder. He wanted to introduce evidence about the truthfulness of his testimony by means of a “systolic blood pressure deception test”, known today as a lie detector or polygraph test. The court refused admissibility of the test, as well as an expert witness testifying about the validity of the test. The three-judge Court of Appeals of the District of Columbia¹⁴⁰ ruled that admissible scientific evidence must be a result of a theory that his test had not gained enough standing and scientific recognition among physiological and psychological authorities to be admitted as evidence to the fact. In particular, the judges in *Frye* ruled that:

“Just when a scientific principle or discovery crosses the line between experimental and demonstrable stages is difficult to define. Somewhere in this twilight zone the evidential force of the principle must be recognized, and while courts will go a long way in admitting expert testimony deduced from a well-recognized scientific principle or discovery, the thing from which the deduction is made must be sufficiently established to have gained general acceptance in the particular field in which it belongs.”¹⁴¹

¹³⁸ Equal Justice “Flaws in forensic” 2018.

¹³⁹ *Frye v. United States*, 421 US 542 - Supreme Court 1975.

¹⁴⁰ *Frye v. United States*, 293 F. 1013 (D.C. Cir. 1923).

¹⁴¹ Giannelli PC “The admissibility of Novel Scientific Evidence: *Frye v. United States*, a half-century later” *Databases*, 1980 *Columbia Law Review* 80(6):1197-1250.

This ruling set new standards for admissibility of expert testimony in courts governed by the “general acceptance” test. Until that time, expert witness testimony was admissible only when “the thing from which the deduction is made” had been “sufficiently established to have gained general acceptance in the particular field in which it belongs”.¹⁴² By the 1970s the majority of state and federal courts adopted the *Frye* test (to date still half of the states use the *Frye acceptance rule* for admissibility of evidence). Judges were given a broad discretion to admit a wide range of scientific evidence.¹⁴³ The *reliability rule* provided a guide for the admissibility of scientific evidence to contribute to the truth determining function of trials. Three factors important to the reliability of evidence were derived from scientific principles:

- 1) the validity of the underlying principle,
- 2) the validity of the technique applying that principle and,
- 3) the proper application of the technique on a particular occasion.

However, the courts used the terms *validity*¹⁴⁴ and *reliability*¹⁴⁵ interchangeably, although these have different meanings in the science community. Validity includes reliability, but the converse is not necessarily true.¹⁴⁶ The first two factors are only critical with regard to admissibility of scientific evidence, when the technique used is in its early developmental stages. Once the technique is sufficiently established, the court will take judicial notice of the principle underpinning the technique,

¹⁴² *Frye v. United States* 1923

¹⁴³ Goss PJ *et al.* “Clearing Away the Junk: Court-Appointed Experts, Scientifically Marginal Evidence, and the Silicone Gel Breast Implant Litigation” 2001 *Food & Drug Law J.* 227-230. (“Junk science gained its ascendancy in part due to the broad discretion *Frye* gave judges to admit marginal scientific evidence.”). Also, Caudill DS “Give Me a Line in a U.S. Supreme Court Opinion or in Official Commentary to the Rules of Evidence for Admissibility of Experts in Court, and I Will Move the [Legal] World” 2002 *HOUS L Rev* (39):437-439. (Noting that “if a proposition was generally accepted by scientists, it was admissible”).

¹⁴⁴ “*Validity*” refers to the ability of a test procedure to measure what it is supposed to measure-its accuracy.

¹⁴⁵ “*Reliability*” refers to whether the same results are obtained in each instance in which the test is performed-its consistency.

¹⁴⁶ Gianelli PC “The Admissibility of Novel Scientific Evidence: *Frye v. United States*, a Half-Century Later” 1980 *Columbia Law Rev* 80(6):1197-1250. Also, Barland “The Reliability of Polygraph Chart Evaluations, in *Legal Admissibility of the Polygraph*” 1975 *N Ansley ed* 120-121.

and relieving the offering party of the burden of producing evidence on past issues.¹⁴⁷ The principles underlying fingerprints¹⁴⁸ and firearms identification,¹⁴⁹ which will be discussed elsewhere in this dissertation, have been judicially recognised based on the first two factors as far back as 1936 and 1949 respectively. The polygraph testing evidence in *United States v Frye* fell short of the acceptance criteria and was ruled not yet to be accepted by the relevant scientific community.

A group of critics viewed the “*general acceptance test*” as delegating legal decisions to scientists, which was said to impose an unfair burden on plaintiffs.¹⁵⁰ Another group argued the test substituted for real analysis of the reliability and validity of proffered testimony.¹⁵¹ The effectiveness of *Frye* in keeping doubtful science out of the courts depended on whom the judges considered to be included in their definition of the “*relevant scientific community*.” But as decades passed and the forensic disciplines gained greater influence, judges tended to restrict their definition of the “*relevant scientific community*” to the forensic examiners themselves. Prosecutors point to guilty verdicts as evidence that the science through expert testimony brought to court, was sound. In this circular way, legal rulings, which never really vetted the science to begin with, substituted real and scientific proof. According to Crist and Requarth,¹⁵² the fatal flaw in *Frye* was that nowhere in the process was anyone required to provide empirical evidence that the techniques actually performed as maintained. They claimed that as *Frye* aimed to keep pseudoscience out of the courts, it has instead helped to create the perfect conditions to keep it in.

¹⁴⁷ Keeffe AJ *et al.* “Sense and Nonsense about Judicial Notice” 1950 *Stan L Rev* 664(2):670-671.

¹⁴⁸ *Piquett v. United States*, 81 F.2d 75 (7th Cir.), cert. denied, 298 U.S. 664 (1936); *State v. Rogers*, 233 N.C. 390, 64 S.E.2d 572 (1951); *Grice v. State*, 142 Tex. Crim. 4, 151 S.W.2d 211 (1941).

¹⁴⁹ *State v. Hackett*, 215 S.C. 434, 55 S.E.2d 696 (1949).

¹⁵⁰ *Reed v. State*, 283 Md. 374, 382, 391 A.2d 364, 368 (1978). (“This criterion of ‘general acceptance’ in the scientific community has come to be the standard in almost all of the courts in the country which have considered the question of the admissibility of scientific evidence.”). Accord, *United States v. Alexander*, 526 F.2d 161, 163 n.3 (8th Cir. 1975). But see Lempert R and Saltzburg S “*A Modern Approach to Evidence*” (St. Paul Minnesota West Publishing 1977) 934-35 (questioning influence of *Frye* test).

¹⁵¹ Foster KR and Huber PW *Judging Science, Scientific knowledge and the Federal Courts* (MIT Press 1999) 11.

¹⁵² Crist M and Requarth T “Forensic Science Put Jimmy Genrich in Prison for 24 Years. What if It Wasn’t Science?” 2018-02-01 *The Nation*.

Preceding cases on forensic discipline specific rulings under the Frye's "*general acceptance*" rule will be discussed in further chapters dealing with specific forensic disciplines. These chapters will show how the *Frye* acceptance rule "exposed" the science and provided for better control of the so-called "pseudoscience".

3.3.1.2 Proclamation of Federal Rule of Evidence FRE702

The *Frye* decision reigned as a lone standing rule for almost 70 years before the Federal Rules of Evidence were adopted by order of the Supreme Court on 20 November, 1972, transmitted to Congress by the Chief Justice on 5 February, 1973, becoming effective on 1 July, 1973.¹⁵³ The idea of codifying a uniform set of Federal Rules of Evidence (FRE) dated back to 1938, when former Attorney General William D. Mitchell wanted an advisory committee to revise the rules of evidence and compose them into a new set of rules.¹⁵⁴ That was never realised, however, and for the next 20 years a number of articles published in the Harvard Law Review, Vanderbilt Law Review, and Insurance Law Journal discussed the adoption of uniform rules.¹⁵⁵

In 1958, the House of Delegates of the American Bar Association (ABA) recommended the formulation of uniform rules and the Judicial Conference established a committee on Rules of Practice and Procedure. A sub-committee was appointed in 1961 with the task to make recommendations on the advisability and feasibility of uniform standards. A report by the committee under chairmanship of Prof. James William Moore was submitted on February 12, 1962 along with the work of Prof. Thomas F. Green Jr. (University of Georgia Law School). At the time, courts followed state rules which existed since 1789. The Criminal Rules of Procedure 26 and 27 dealt with evidence. Rule 26 stated:

¹⁵³American Bar Association https://apps.americanbar.org/litigation/litigationnews/trial_skills/061710-trial-evidence-federal-rules-of-evidence-history.html (Date of use: 14 June 2018).

¹⁵⁴ Judicial Conference of the United States' Committee on Rules of Practice and Procedure, Rules of Evidence; A Preliminary Report on the Advisability and Feasibility of Developing Uniform Rules of Evidence for the U.S. District Courts 1 (1962) quoting Proceedings of Cleveland Institute on Federal Rules 186 (1938).

¹⁵⁵ American Bar Association *Rules of evidence* 1958.

“In all trials the testimony of witnesses shall be taken orally in open court, unless otherwise provided by an act of Congress or by these rules. The admissibility of evidence and the competency and privileges of witnesses shall be governed, except when an act of Congress or these rules otherwise provide, by the principles of the common law as they may be interpreted by the courts of the United States in the light of reason and experience.”

The rules were in a poor state according to Advisory Committee notes.¹⁵⁶ Chief Justice Warren appointed another advisory committee in 1965, which consisted of trial lawyers, federal judges, and law professors to write the new Federal Rules of Evidence. The first draft was sent out in 1969, but it was far from the finished version signed into law. It was submitted to Congress in 1972 and signed into law in 1975.¹⁵⁷ What seemed like a simple task, which had to be completed with a sense of urgency took 30 years for completion. There were 67 individually numbered rules, divided among 11 articles. The rules govern the introduction of all evidence for civil and criminal proceedings in federal courts. Many State courts’ rules closely resemble the FRE. The rules address how evidence should be handled in the courts and how expert witnesses should present evidence. The FRE assist to ensure that juries ultimately consider only admissible materials and the relevant evidence when deciding a verdict. The FRE, in the originally drafted form did not contain any rules providing direction on ensuring that scientific testimony is reliable or has been generally accepted. Scientific evidence was regarded as similar to any other piece of evidence presented to the court. Since the adoption of the rules, a number of amendments were made, aimed at better defining and clarifying the purposes.¹⁵⁸ The Federal Rules of Evidence relevant to forensic science and the law is summarised in Table 3.1. below:¹⁵⁹

Table 3.1 Summary of Federal Rules of Evidence relevant to scientific evidence

Rule of Evidence	Summary
104(a)	<i>This rule requires the trial judge to determine as a preliminary matter before the jury hears the <u>evidence whether experts are qualified and whether their testimony will be admitted.</u></i>

¹⁵⁶ American Bar Association “Rules of evidence” 1958.

¹⁵⁷ Federal Rules of Evidence, 1975.

¹⁵⁸ Legal Information Institute “Federal Rules of Evidence: Testimony by Expert Witnesses” 2000-04-17 and 2011-04-26. Rule 702 has been amended in response to *Daubert v. Merrell Dow Pharmaceuticals, Inc.*, 509 U.S. 579 (1993), and to the many cases applying *Daubert*, including *Kumho Tire Co. v. Carmichael*, 119 S.Ct. 1167 (1999).

¹⁵⁹ Legal Information Institute <https://www.law.cornell.edu/rules/fre> (Date of use: 12 December 2019).

401	<i>This rule defines what evidence is relevant in a case. It defines evidence as relevant if it <u>has any tendency to make a fact that is material to the outcome of the case either more probable or less probable than it would have been without the evidence.</u></i>
402	<i>This rule prohibits the admission of evidence that is not relevant.</i>
403	<i>This rule allows the trial judge to exclude evidence that is relevant, if its probative value (its value in proving issues that determine the outcome of the case) is <u>substantially outweighed by certain adverse consequences such as unfair prejudice, delay of the trial, confusion of the jury, or if the evidence is unnecessarily cumulative.</u> It requires the judge to balance the positive qualities of the evidence against the inimical consequences of admitting it.</i>
702	<i>This rule provides that scientific, technical or specialised evidence (i.e. “Expert testimony”) may be admitted if: (a) the <u>expert is qualified;</u> (b) the <u>expert’s testimony will help the jury decide issues in the case or understand the evidence;</u> and (c) the <u>expert’s testimony is based on sufficient facts or data; is the product of reliable methods and principles, and if the expert reliably has applied the methods and principles to the facts of the case in trial.</u></i>
703	<i>This rule identifies the types of factual information that an expert witness may rely on to support an opinion. Included are facts perceived by the expert through her own study or research, facts provided to her by others (including the lawyer), or facts learned of by the expert from other witnesses during the trial. The rule allows the expert to base her opinion on information that is reliable to practitioners in her field, even if it is not admissible into evidence. (For example, a neuropsychologist may rely on a report by the patient’s psychiatrist that might be inadmissible hearsay in forming opinions about the condition of a patient.) If the expert bases her opinion in whole or part on reliable but inadmissible facts, the trial judge must decide whether the jury is informed of these particular facts for the purpose of evaluating the weight to be given to the expert’s testimony.</i>
704	<i>This rule allows the expert to express opinions about “ultimate facts”—those that determine which party will win or lose the case. Thus, an expert could express the opinion that a plaintiff’s emotional injuries were caused by the harassing conduct of the defendant in an employment discrimination case.</i>

705	<i>This rule allows an expert to testify to the jury about her opinions without first stating all the facts that underlie them, unless the trial judge requires them to be disclosed. Note, however, that under Rule 104(a), the party offering the expert's testimony must already have demonstrated to the trial judge that the expert's opinion was based on sufficient facts; otherwise, the expert would not be qualified to testify before the jury.</i>
706	<i>This rule allows the trial judge to retain an expert witness to act as a court expert, to help the judge deal with conflicts in expert evidence between the parties' experts.</i>
1101(de)(1)	<i>This rule allows the trial judge to disregard all rules of evidence except those dealing with privilege when deciding, outside the presence of the jury, whether to admit expert testimony.</i>

The amended FRE 702 deals specifically with the admission of expert testimony. It states as follows:

“If scientific, technical, or other specialized knowledge will assist the trier-of-fact to understand the evidence or to determine a fact in issue, a witness qualified as an expert by knowledge, skill, experience, training, or education, may testify thereto in the form of an opinion or otherwise, if (1) the testimony is based upon sufficient facts or data, (2) the testimony is the product of reliable principles and methods, and (3) the witness has applied the principles and methods reliably to the facts of the case.”

The three-part test under the revised FRE 702 supplants earlier tests announced in opinions of the United States Supreme Court. One of interest is *U.S. v. Monteiro and five others*,¹⁶⁰ where the qualifications or the lack of qualifications of the expert were challenged by the defence. A requirement of FRE 702 is that the judge must ensure that the expert is qualified by “knowledge, skills, experience, training, or education”. In many cases, the defence misinterpreted the “or” factor in being qualified.

¹⁶⁰ *U.S. v. Monteiro and five others*, 871 F.2d 204 (1st Cir. 1989).
<https://afte.org/uploads/documents/swggun-usvmonteiro.pdf> (Date of use: 6 June 2019).

Judge Saris ruled that the ballistic expert witness, Weddleton, had not yet attained a college degree, but stated that education is not the *sine qua non* of qualification for recognition as an expert witness.¹⁶¹ Although Weddleton did not have formal scientific training, was neither certified by, nor a member of any professional organisation, and had not completed proficiency testing at that time, he performed hundreds of examinations, and was, by the standards of experience in the field of firearm examination, qualified.

Although the American Society of Crime Laboratory Directors (ASCLD), the governing entity for crime laboratories, listed a bachelor's degree with science courses as a "desirable" qualification for firearm examiners, it did not list it as "essential".¹⁶²

Some judges interpreted the 1975 rules as allowing almost any testimony said to be "scientific" to be presented to the jury, whereas other judges stayed with the acceptance test of *Frye*. The permissibility of more science-based testimony gave birth to the "pseudoscience testimony" concept that had little basis in reality.¹⁶³ Even with the FRE702, there was a need for more criteria on scientific evidence relevance and reliability.

The FRE 702 rule has evolved over time to give the trial court a more activist role in determining the admissibility of expert testimony. Some States still adhere to *Frye* and give the scientific community the lead role in determining general acceptance, but approximately half of the States and the Federal courts have placed the ultimate decision on reliability in the hands of the judge.

3.3.1.3 Birth of the "Gatekeeper" rule

¹⁶¹ See Federal Rules of Evidence (FRE) 702 advisory committee's note (noting that the "text of Rule 702 expressly contemplates that an expert may be qualified on the basis of experience"); *County of Riverside v. McLaughlin*, 500 U.S. 44 (1991) at § 702.04[1][a]. See also *Poulis-Minott v. Smith*, 388 F.3d 354 (2004) at 360 (affirming trial court's allowing testimony from a fishing boat captain as to the ability of a captain to respond to certain emergencies under the circumstances).

¹⁶² American Society of Crime Laboratory Directors, *Laboratory Accreditation Board Manual*, 29 (1997) (Ex. 49).

¹⁶³ Huber *Galileo's revenge* 1991. One notorious case was *Wells v. Ortho Pharmaceutical Corp.*, 615 F. Supp. 262 (N.D. Ga. 1985).

In 1993, *Daubert v. Merrell - Dow Pharmaceuticals*,¹⁶⁴ the Supreme Court articulated a new set of criteria for the admissibility of scientific expert testimony.¹⁶⁵ In the case a mother used Bendectin, an anti nausea drug, during pregnancy and allegedly caused birth defects in her child. Merrill-Dow, the pharmaceutical company, moved for summary judgment in the case, countering her claim of injury of the child. The affidavit of a physician and epidemiologist, Dr. Steven H. Lamm, who was a respected authority in the area of health risks from exposure to chemical substances, supported the motion of Merrill-Dow. Dr. Lamm stated that he had reviewed 30 published studies involving more than 130,000 patients and that none of those studies had found Bendectin to cause injuries in fetuses. Based on the results of the studies he was of the opinion that the use of Bendectin during any time of the pregnancy was not a risk factor for human birth defects. However, the Daubert plaintiffs presented affidavits from eight different experts who, on the basis of various animal studies, claimed to have found a link between Bendectin and birth defects. This countered the Merrill-Dow's motion, The trial court granted Merrill-Dow's motion, finding that Daubert's experts relied on evidence "not sufficiently established to have general acceptance in the field to which it belongs." The Court found that:

"Since there was a vast body of human epidemiological data in this area, animal cell studies were not sufficient to raise a reasonable jury issue regarding causation and the analysis by these experts, attacking the epidemiological analyses cited by Dr. Lamm based on "recalculations" of data in the previously published studies, were inadmissible as those findings had not been published or subjected to peer review so as to attain "general acceptance" in the field of epidemiology."¹⁶⁶

The Court of Appeals affirmed the trial court's decision based upon the *Frye* standard of general acceptance in the scientific community. The court of Appeals held as follows:

"It is of particular significance that there existed a massive amount of original published studies supporting the safety of Bendectin, all of which had undergone scrutiny by the larger scientific community, while the "re-analyses" by those suggesting the risks of Bendectin were neither published nor subjected to peer review."

¹⁶⁴ *Daubert v. Merrell - Dow Pharmaceuticals, Inc.*, 509 U.S. 579 (1993).

¹⁶⁵ Legal Information Institute "*Daubert et ux., individually and as guardians and litem for Daubert, et al. v. Merrell Dow Pharmaceuticals, Inc*" <https://www.law.cornell.edu/supct/html/92-102.ZS.html> (Date of use: 12 June 2019).

¹⁶⁶ *Daubert v. Merrell - Dow Pharmaceuticals, Inc.*, 509 U.S. 579 (1993), 584

Those findings were considered novel scientific evidence or, as it has since become known as “junk science.” Huber¹⁶⁷ refers to junk science the process where the witness seeks to present grossly fallacious interpretations of scientific data or opinions that are not supported by scientific evidence. He also states that “junk science” is a legal problem, not a scientific one. The adversarial nature of legal proceedings cultivated these types of sciences and the difficulty many lay people have in evaluating technical arguments contributed to the problem.

Under the *Frye* standard, such “junk science” did not qualify as legally admissible expert testimony. The *Frye* standard gives great deference to the views of forensic practitioners and not to empirical testing.¹⁶⁸

The Supreme Court,¹⁶⁹ however, overturned the ruling of the lower courts and new standards of admissibility were created. The Supreme Court, in addressing the facts of *Daubert* relating to scientific evidence and expert testimony, first established a two-step analysis to be used by the Federal district courts in acting as the “gatekeepers” of the introduction of expert testimony. Those criteria were:

- (1) that the evidence is relevant, and
- (2) that it is reliable.

It entails a preliminary assessment of whether the reasoning or methodology underlying the testimony is “scientifically valid” and whether that “reasoning or methodology properly can be applied” to the facts in issue.¹⁷⁰

¹⁶⁷ Huber “Galileo’s revenge” 1991.

¹⁶⁸ Saks MJ “Merlin and Solomon: Lessons from the Law’s Formative Encounters with Forensic Identification Science” 1998 *Hastings Law J* 1069:1138. (“*Frye* does not work because its measure of validity is the judgment of ‘the field,’ and the field may consist of nonsense. For example, the *Frye* doctrine cannot exclude astrology.”).

¹⁶⁹ *Daubert v. Merrell Dow Pharmaceuticals, Inc.*, 43 F. 3d 1311 - Court of Appeals, 9th Circuit 1995.

¹⁷⁰ *Daubert* 509 U.S. [592–93].

In terms of the *Daubert* standard, trial judges will view the validity and reliability of scientific evidence and make a clear decision on their admissibility in court in front of a jury. The jury has a more flexible job of “weighing” the evidence admitted. Commentators from both sides voiced their opinions on the effect of *Daubert* to the courtroom. Those in favour of *Daubert* said it imposed barriers to the use of junk science.¹⁷¹ On the other side, commentators argued that *Daubert* actually relaxes the standard for admitting junk science.¹⁷² There were also a few neutral commentators who claimed the standard remained unchanged after *Daubert*.¹⁷³

In determining the issue of whether the evidence is to be considered reliable, the Court established a separate, non-exclusive four-part test, which asks four questions, namely:

- (1) can the theory or technique be tested,
- (2) has it been subjected to peer review and published,
- (3) is there a known or potential rate of error, and
- (4) is there a level of general acceptance in that particular discipline's community.

Thus, the single-issue *Frye test* was expanded to include these new factors in evaluating the quality, and resulting admissibility, of scientific evidence and expert testimony. Chief Justice Rehnquist warned of the pitfalls inevitably created when the Supreme Court offers “general observations” in its opinions. He noted that in *Daubert* there were 22 *amici curiae* (“friends of the court”) briefs filed by interested groups and individuals, many of which dealt with issues unrelated

¹⁷¹ *Iacobelli Constr., Inc. v. Cnty. of Monroe*, 32 F.3d 19, 25 (2d Cir. 1994); *Graham v. Playtex Prods., Inc.*, 993 F. Supp. 127, 133–34 (N.D.N.Y. 1998); *Smith v. Ford Motor Co.*, 882 F. Supp. 770, 774 n.3 (N.D. Ind. 1995). Also, Owen DG “A Decade of *Daubert*” 2002 (80) *Den U L Rev* 345–46: 353–356.

¹⁷² Whitehead GM “*Daubert* Will Allow More Expert Testimony, Complicate Jurors’ Job” 1993 *Prejudice Defense*, 21 *Prod. Safety & Liability Rep. (BNA)* 41:41–43; see also *State v. Carter*, 524 N.W.2d 763, 777–79 (Neb. 1994) (rejecting *Daubert* and noting that its test is “less demanding” and, therefore, more likely than *Frye* to admit junk science). Evidence suggests that this view is incorrect. Bernstein, *supra* note 39, at 2139–40 (observing that, in the short time after *Daubert* was decided, five federal circuit courts used *Daubert* to exclude evidence, whereas only one court relied on the opinion to admit evidence).

¹⁷³ *People v. Cutter* 12 Crim. L. REP 2133 (1972). See Miller, [501, 515] (“Although *Daubert* has been cited in more than 40 federal court decisions and more than 60 state court decisions across the country as of September 1994, admissibility of expert testimony appears relatively unchanged.”).

to the law, but rather with defining words such as “scientific knowledge”, “the scientific method”, “scientific validity”, and “peer review”. Justice Rehnquist also noted that:

“Questions arise simply from reading this part of the Court's opinion, and countless more questions will surely arise when hundreds of district judges try to apply its teaching to particular offers of expert testimony. Does all of this dicta apply to an expert seeking to testify on the basis of "technical or other specialized knowledge" - the other types of expert knowledge to which Rule 702 applies - or are the "general observations" limited only to "scientific knowledge"? What is the difference between scientific knowledge and technical knowledge; does Rule 702 actually contemplate that the phrase "scientific, technical, or other specialized knowledge" be broken down into numerous sub-species of expertise, or did its authors simply pick general descriptive language covering the sort of expert testimony which courts have customarily received?”¹⁷⁴

The Supreme Court also noted that “*the inquiry is a flexible one*” and that “*the focus, of course, must be solely on principles and methodology, not on the conclusions that they generate*”.¹⁷⁵ The Court continued to summarise its views by stating:

“Vigorous cross-examination, presentation of contrary evidence, and careful instruction on the burden of proof are the traditional and appropriate means of attacking shaky, but admissible evidence.....These conventional devices, rather than wholesale exclusion under an uncompromising ‘general acceptance’ test, are the appropriate safeguards where the basis of scientific testimony meets the standards of Rule 702”.¹⁷⁶

The sentence quoted above in *Daubert* emphasises that *Frye’s test* which focuses on “general acceptance” was replaced with *Daubert’s* focus on “reliability” and “validity” of scientific knowledge/methods – standards of Rule 702. Historically, scientists had to come to agreement about the validity of particular theories. The ultimate test for validity of a theory in science or data collection, is time. One concept in science regarding testing validity is that over time, the theory is scrutinised and many times is self-correcting. This point will be canvassed in more detail in the chapters dealing with the respective forensic disciplines.

¹⁷⁴ *Daubert* 509 U.S. 579 (1993).

¹⁷⁵ *Daubert* 509 U.S. [594-595].

¹⁷⁶ *Daubert* 509 U.S. [596].

Most of the state courts were divided on whether to follow *Daubert* or to continue using the *Frye* standard. Of all the state courts that decided to follow *Daubert*, all but two (Georgia and Connecticut) had standards on expert testimony similar to federal Rule 702. A number of courts in those jurisdictions have applied *Daubert* to certain scientific evidence cases only. Other states, including several with evidence rules analogous to Rule 702, have opted to still follow the *Frye* standard.¹⁷⁷

Based on the outcome of *Daubert*, numerous courts had to address the unresolved question whether the *Daubert* factors by which reliability was to be tested should also be applied to experts offering opinion testimony not based on clearly identified scientific principles, but which sprung from “technical or other specialized knowledge?” This question was later resolved in the case of *Kumho Tire*, discussed below.

3.3.1.4 Daubert factors not applicable to all forms of expert opinion testimony

In 1999, in *Supreme Court of the United States, Kumho Tire CO., LTD., et al. v. Carmichael et al.*,¹⁷⁸ the plaintiffs were the survivors of an automobile accident that occurred after a tire on the family's minivan failed. They instituted a suit against the tire's manufacturer and its distributor (collectively Kumho Tire), claiming that the tire that failed was defective. Dennis Carlson, Jr., a tire failure analyst, intended to state in his expert opinion that a defect in the tire's manufacture or design caused the tyre to blow out. He based his opinion on visual and tactile inspections of the tire, and upon the theory that in the absence of at least two of four specific, physical symptoms indicating tire abuse, the tire failure of the kind that occurred in the mentioned case was caused by a defect. To counter this, Kumho Tire moved to exclude Carlson's testimony on the ground that his methodology failed to satisfy Federal Rule of Evidence 702, which stated a witness must be qualified as an expert to testify in the form of an opinion.

¹⁷⁷ Giannelli PC and Imwinkelried “*Scientific Evidence*” (Lexis Nexus 5th ed 2012).

¹⁷⁸ *Kumho Tire Co. v. Carmichael*, 526 US 137 - Supreme Court 1999.

Granting the motion, the District Court acknowledged that it should act as a reliability “gatekeeper” under *Daubert v. Merrell Dow Pharmaceuticals*,¹⁷⁹ in which the latter court held that Rule 702 imposes a special obligation upon a trial judge to ensure that scientific testimony is not only relevant, but reliable. The court noted that *Daubert* discussed four factors, namely testing, peer review, error rates, and “acceptability” in the relevant scientific community, which might prove helpful in determining the reliability of a particular scientific theory or technique,¹⁸⁰ and found that those factors argued against the reliability of Carlson’s methodology. On the plaintiffs’ motion for reconsideration, the court agreed that *Daubert* should be applied flexibly, that its four factors were simply illustrative, and that other factors could be argued in favour of admissibility.

In reversing the District Court’s decision in the *Kumho tire* case, the Eleventh Circuit held that the District Court had erred as a matter of law in applying *Daubert*. Believing that *Daubert* was limited to the scientific context, the court held that the *Daubert* factors did not apply to Carlson’s testimony, which it characterised as skill- or experience-based.

The Court ruled as follows:

“The *Daubert* “gatekeeping” obligation applies not only to “scientific” testimony, but to all expert testimony. There is no distinction by Rule 702 between “scientific” knowledge and “technical” or “other specialized” knowledge, but makes clear that any such knowledge might become the subject of expert testimony. It is the Rule’s word “knowledge,” not the words (like “scientific”) that modify that word that establishes a standard of evidentiary reliability. 509 U.S., at 589—590. *Daubert* referred only to “scientific” knowledge because that was the nature of the expertise there at issue. *Id.*, at 590, n. 8. Neither is the evidentiary rationale underlying *Daubert*’s “gatekeeping” determination limited to “scientific” knowledge. Rules 702 and 703 grant all expert witnesses, not just “scientific” ones, testimonial latitude unavailable to other witnesses on the assumption that the expert’s opinion will have a reliable basis in the knowledge and experience of his discipline. *Id.*, at 592. Finally, it would prove difficult, if not impossible, for judges to administer evidentiary rules under which a “gatekeeping” obligation depended upon a distinction between “scientific” knowledge and “technical” or “other specialized” knowledge, since there is no clear line dividing the one from the others and no convincing need to make such distinctions. Pp. 7—9.

¹⁷⁹ *Daubert* 509 U.S. [579, 589].

¹⁸⁰ *Daubert* 509 U.S. [593-594].

A trial judge determining the admissibility of an engineering expert's testimony may consider one or more of the specific Daubert factors. The emphasis on the word "may" reflects Daubert's description of the Rule 702 inquiry as "a flexible one." 509 U.S., at 594. The Daubert factors do not constitute a definitive checklist or test, *id.*, at 593, and the gatekeeping inquiry must be tied to the particular facts, *id.*, at 591. Those factors may or may not be pertinent in assessing reliability, depending on the nature of the issue, the expert's particular expertise, and the subject of his testimony. Some of those factors may be helpful in evaluating the reliability even of experience-based expert testimony, and the Court of Appeals erred insofar as it ruled those factors out in such cases. In determining whether particular expert testimony is reliable, the trial court should consider the specific Daubert factors where they are reasonable measures of reliability. Pp. 10—12.

The court of appeals must apply an abuse-of-discretion standard when it reviews the trial court's decision to admit or exclude expert testimony. *General Electric Co. v. Joiner*, 522 U.S. 136, 138—139. That standard applies as much to the trial court's decisions about how to determine reliability as to its ultimate conclusion. Thus, whether Daubert's specific factors are, or are not, reasonable measures of reliability in a particular case is a matter that the law grants the trial judge broad latitude to determine. See *id.*, at 143. The Eleventh Circuit erred insofar as it held to the contrary. P. 13."¹⁸¹

By 2000, the Supreme Court, in the case of *Weisgram v. Marley*,¹⁸² described *Daubert* as establishing an "exacting" standard. In the same year, FRE 702 was amended to incorporate the *Daubert/Kumho* standard.¹⁸³ In addition, an extensive study of reported criminal cases found that "the Daubert decision did not impact on the admission rates of expert testimony at either the trial or appellate court levels".¹⁸⁴

The standard that the United States trial courts are to use after *Daubert*, *Kumho*, and *FRE702* (2000 amendment), set forth the four-part test which is currently applied today:

- The expert's scientific, technical, or other specialised knowledge will help the trier of fact to understand the evidence and to determine the fact in issue,
- The testimony is based on sufficient facts or data,

¹⁸¹ *Kumho*, (97-1709) 526 U.S. 137 (1999) 131 F.3d 1433, reversed.

¹⁸² *Weisgram v. Marley Co.*, 528 U.S. 440, 455 (2000).

¹⁸³ After *Daubert*, the Court decided *General Elec. Co. v. Joiner*, 522 U.S. 136 (1997), which established the standard for appellate review (abuse of discretion) for applying the *Daubert* factors. *Daubert*, *Joiner*, and *Kumho* make up what is known as the *Daubert Trilogy*.

¹⁸⁴ Groscup J *et al.* "The Effects of Daubert on the Admissibility of Expert Testimony in State and Federal Criminal Cases" 2002 *Psyc Public Policy and Law* 8(4):339–372.

- The testimony is the product of reliable principles and methods, and
- The expert has reliably applied the principles and methods to the facts of the case.

Only about half of the states have followed the federal courts in amending their versions of FRE702. The majority of the states not following *Daubert* have decided to remain with the *Frye* standard under which novel scientific expert theories are examined to determine whether they have been “generally accepted” within the relevant scientific community.

It is important for legal professionals to familiarise themselves with the relevant criteria or standard that is followed in the legal jurisdiction where they will be practising law.

The impact of the *Frye* “general acceptance” standard, FRE702, and the *Daubert* and *Kumho* acceptance criteria, will be discussed in more detail in subsequent chapters relating to the four forensic disciplines elsewhere in this thesis.

Although the role of expert witnesses and the admissibility of evidence had been comprehensively addressed within the United States, other countries experienced similar challenges and changes to accommodate both evidence and testimony from experts in court proceedings.

3.3.2 *The United Kingdom*

3.3.2.1 Expert testimony

Expert testimony in the United Kingdom also has a long history, dating back to the early 14th century.¹⁸⁵ According to Meyer,¹⁸⁶ Wigmore’s comments regarding expert evidence during the early 19th century (referred to paragraph 3.1 above) were made in respect of a period when the admissibility of expert testimony was allowed in any legal procedure. Since then, the knowledge and technology expanded in such a way that scientists were forced to specialise in specific scientific disciplines, such as chemistry and biology.

¹⁸⁵ Meyer *Expert witnessing* 1999: [2].

¹⁸⁶ Meyer *Expert witnessing* 1999: [3].

English and Welsh courts did not require an expert witness to be academically qualified to testify.¹⁸⁷ It was only necessary to have relevant experience and knowledge within the specified discipline to be considered an expert witness.¹⁸⁸ The United Kingdom used the Roman law as a guide to drafting formalised policies and procedures ensuring rules for courts.¹⁸⁹ The Rules of Supreme Courts (RSC) were created in 1883 and were made up of Orders and Acts of Parliament. By 1951, the RSC consisted of 144 Orders and Rules, and nine Acts of Parliament as amendments, which were made over time.¹⁹⁰ In 1951, the Evershed Committee on Supreme Court Practice and Procedure published its Second Interim Report in which it was strongly recommended that “a complete revision of the Rules be immediately put in hand”.¹⁹¹ The revised RSC came into force on 1 October 1966.

The courts approved Lord Mansfield’s opinion in *Folkes v. Chadd* in many jurisdictions. In *R v. Turner* in 1975, the court stated that:

“The foundation of the rules was laid by Lord Mansfield CJ in *Folkes v. Chadd* (1782): ‘The opinion of scientific men upon proven facts may be given by men of science within their own science’. An expert opinion is admissible to provide the court with scientific information which is likely to be outside of the experience of a judge or jury. If, on the proven facts, a judge or jury can form their own conclusions without help, then the opinion of an expert is unnecessary. In such a case, if it is dressed up in scientific jargon it may make the judgment more difficult. The fact that an expert witness has impressive scientific qualifications does not by that fact alone make his opinion any more helpful than that of the jurors themselves; but there is a danger that they may think it does”.¹⁹²

¹⁸⁷ Meintjes-Van der Walt "The presentation of expert evidence at trials in South Africa, the Netherland and England and Wales" 2001 *Stellenbosch Law Rev* 2:241.

¹⁸⁸ Meintjes-Van der Walt *Expert evidence* 2001 [241].

¹⁸⁹ A Brief History of the Rules of Court <http://www.duhaime.org/LawMuseum/LawArticle-1591/A-Brief-History-of-the-Rules-of-Court.aspx> (Date of use: 2 February 2020). In Roman times, one did not just walk into the Court, take a number, and when called, state their case. No. Any perusal of Justinian and Tribonian's work in 533 A.D. would quickly prove that the Romans liked their procedure. Specific legal actions had specific Latin names. For those unfamiliar with Roman law, consider these words in Reeves' History of the English Law: "In nothing was the Roman law more remarkable than in the importance in attached to procedure, the practical part of law, the actual means and processes by which justice is obtained and administered "The Roman law provided a remedy for every injury and a proper procedure for every remedy." Civil procedure, rules of court, were covered in the 450-448 B.C. Twelve Tables of Roman law.

¹⁹⁰ The Supreme Court Practice 1967 Volume 1 Preface to the 1st ed.

¹⁹¹ Evershed Committee on Supreme Court Practice and Procedure Second. *Interim Report in 1951 (Cmd 8176 para 117)*.

¹⁹² *R. v. Turner*, [1975] 1 All ER 70.

In the case of *R v. Robb*, the Court of Appeal analysed what constituted novel science and concluded as follows:

“The old academically established sciences such as medicine, geology or metallurgy and established professions ... present no problem. The field will be regarded as one in which expertise may exist and any qualified member will be accepted without question as an expert. Expert opinions may be given of the quality of commodities, or the literary, artistic, scientific or other merit of works alleged to be obscene. Yet while receiving this evidence the courts would not accept the evidence of an astrologer, soothsayer, a witch-doctor or an amateur psychologist and might hesitate to receive evidence of attributed authorship on stylometric analysis.”¹⁹³

3.3.2.2 Legislation on expert testimony and admissibility

In June 1995, in an interim report,¹⁹⁴ Lord Wolf recommended changes to the RSC litigation after seeing the results of a survey carried out by the National Consumer Council,¹⁹⁵ which found that three out of four people who were involved in serious legal disputes were dissatisfied with the civil justice system. On 26 April, 1999, the RSC were replaced by the new Civil Procedure Rules (CPR) and were designed to improve access to justice by making legal proceedings cheaper, quicker, and easier to understand for non-lawyers. Civil Procedure Rule 35 captured most requirements for expert testimony and written reports:¹⁹⁶ Table 3.2 below provides a summary of Rule 35.

Table 3.2: Summary of Rule 35 of the Civil Procedure Rules

Contents of this Part Title	Number
Duty to restrict expert evidence	Rule 35.1

¹⁹³ *R. v. Robb*, [1991] 93 Cr. App. R. 161.

¹⁹⁴ Slapper G and Kelly D *The English Legal System* (Routledge Cavendish 7th ed Chapter 9 The Civil Process 2004) 776.

¹⁹⁵ Seeking Civil Justice: A survey of people's needs and experiences, 1995, NCC.

¹⁹⁶ Ministry of Justice, Part 35, *Experts and Assessors* http://www.justice.gov.uk/courts/procedure-rules/civil/rules/part35#rule35_4 (Date of use: 9 December 2019).

Interpretation and definitions	Rule 35.2
Experts – overriding duty to the court	Rule 35.3
Court’s power to restrict expert evidence	Rule 35.4
General requirement for expert evidence to be given in a written report	Rule 35.5
Written questions to experts	Rule 35.6
Court’s power to direct that evidence is to be given by a single joint expert	Rule 35.7
Instructions to a single joint expert	Rule 35.8
Power of court to direct a party to provide information	Rule 35.9
Contents of report	Rule 35.10
Use by one party of expert’s report disclosed by another	Rule 35.11
Discussions between experts	Rule 35.12
Consequence of failure to disclose expert’s report	Rule 35.13
Expert’s right to ask court for directions	Rule 35.14
Assessors	Rule 35.15

The Civil Procedure Rule 35.4 makes provision for the court to decide on the admissibility of an expert witness. The rule states as follows:

- “(1) No party may call an expert or put in evidence in an expert’s report without the court’s permission.
- (2) When a party applies for permission under this rule he must identify -
 - (a) the field in which he wishes to rely on expert evidence; and
 - (b) where practicable the expert in that field on whose evidence he wishes to rely.
- (3) If permission is granted under this rule it shall be in relation only to the expert named or the field identified under paragraph (2).
- (4) The court may limit the amount of the expert’s fees and expenses that the party who wishes to rely on the expert may recover from any other party.”

Rule 35.5 (1) stipulates the general requirement for expert testimony is submission of a written report before testimony:

- “(1) Expert evidence is to be given in a written report unless the court directs otherwise.
- (2) If a claim is on the fast track, the court will not direct an expert to attend a hearing unless it is necessary to do so in the interests of justice.”

With this rule, the experts' time is not wasted by attending court hearings if there is no dispute within their written reports. The admissibility of expert testimony in criminal cases was added in the Criminal Justice Act of 1988,¹⁹⁷ which refers to expert reports as follows:

- “(1) An expert report shall be admissible as evidence in criminal proceedings, whether or not the person making it intends to give oral evidence in those proceedings.
- (2) If it is proposed that the person making the report shall not give oral evidence, the report shall only be admissible with the leave of the court.
- (3) For the purpose of determining whether to give leave, the court shall have regard—
 - (a) to the contents of the report;
 - (b) to the reasons why it is proposed that the person making the report shall not give oral evidence;
 - (c) to any risk, having regard in particular to whether it is likely to be possible to controvert statements in the report if the person making it does not attend to give oral evidence in the proceedings, that its admission or exclusion will result in unfairness to the accused or, if there is more than one, to any of them; and
 - (d) to any other circumstances that appear to the court to be relevant.
- (4) An expert report, when admitted, shall be evidence of any fact or opinion of which the person making it could have given oral evidence.
- (5) In this section, “expert report” means a written report by a person dealing wholly or mainly with matters on which he is (or would be if living) qualified to give expert evidence.”

In the case of *Anglo Group PLC v. Winther Brown & Co*,¹⁹⁸ the role of the expert is described as follows:

“An expert witness should at all stages in the procedure, on the basis of the evidence as he understands it, provide independent assistance to the court and the parties by way of objective, unbiased opinion in relation to matters within his expertise. An expert should never assume the role of an advocate.

The expert's evidence should normally be confined to technical matters on which the court will be assisted by receiving an explanation, or to evidence of common professional practice. The expert witness should not give evidence or opinions as to what the expert

¹⁹⁷ The National Archives, Criminal Justice Act 1988, Part III, Section 30, *Public General Acts* <http://www.legislation.gov.uk/ukpga/1988/33/section/30> (Date of use: 9 December 2019).

¹⁹⁸ *Anglo Group PLC v. Winther Brown & Co* (2002) 72 Con LR 118, T & CC.

himself would have done in similar circumstances or otherwise seek to usurp the role of the judge.”¹⁹⁹

Quotes from *Frye* and *Daubert* have also been cited in English judgments. In *R v. Gilfoyle*,²⁰⁰ the Court of Appeal approved the general acceptance rule to accept admissibility of expert evidence on a psychological autopsy. Also in *R v. Dallagher*,²⁰¹ *Daubert* was quoted with regard to the admissibility of ear print evidence.

In 2009, in the case of *R v. Reed and Garmson*,²⁰² the Court of Appeal provided a three-pronged admissibility approach to expert evidence rules. The Court stated that:

“It is important to distinguish the issue of the admissibility of expert evidence from the assessment of that evidence by the jury. In the present appeal, the issue related to admissibility.

First, expert evidence of a scientific nature is not admissible where the scientific basis on which it is advanced is insufficiently reliable for it to be put before the jury. There is, however, no enhanced test of admissibility for such evidence. If the reliability of the scientific basis for the evidence is challenged, the court will consider whether there is a sufficiently reliable scientific basis for that evidence to be admitted, but, if satisfied that there is a sufficiently reliable scientific basis for the evidence to be admitted, then it will leave the opposing views to be tested in the trial.

Second, even if the scientific basis is sufficiently reliable, the evidence is not admissible unless it is within the scope of evidence an expert can properly give.

Third, unless the admissibility is challenged, the judge will admit that evidence. That is the only pragmatic way in which it is possible to conduct trials, as sufficient safeguards are provided by Part 3 and Part 33 of the Criminal Procedure Rules. However, if objection to the admissibility is made, then it is for the party proffering the evidence to prove its admissibility.”

In the case of *Ikarian Reefer*,²⁰³ Cresswell J laid down rules for expert conduct and reminded experts of their obligation of an expert witness, summarised as follows:

¹⁹⁹ Knoetze I “Regsvergelykende studie van deskundige getuienis in straf- en siviele verhore” (Translated as “Legal comparative studie of expert witnesses in criminal and civil hearings”) (Doctor Legum Dissertation University of the Free State, 2005).

²⁰⁰ *R. v. Gilfoyle*, 2001. 2 Cr App r 5.

²⁰¹ *R. v. Mark Dallagher*, [2002] EWCA Crim 1903.

²⁰² *R. v. Reed, Reed and Garmson*, [2009] EWCA Crim 2698.

²⁰³ National Justice Cia Naviera SA v. Prudential Assurance Co Ltd, *The Ikarian Reefer*, [1993] 2 Lloyd's Rep 68 [81].

- Expert evidence presented to the court should be and seen to be the independent product of the expert uninfluenced as to form or content by the exigencies of litigation.
- An expert witness should provide independent assistance to the court by way of objective unbiased opinion in relation to matters within his expertise. An expert witness in the High Court should never assume the role of advocate.
- An expert witness should state the facts or assumptions on which his opinion is based. He should not omit to consider material facts which detract from his concluded opinions.
- An expert should make it clear when a particular question or issue falls outside his expertise.
- If an expert's opinion is not properly researched because he considers that insufficient data is available then this must be stated with an indication that the opinion is no more than a provisional one.
- If after exchange of reports, an expert witness changes his view on material matters, such change of view should be communicated to the other side without delay and when appropriate to the court.

The above rules of expert conduct was reiterated in the later Court of Appeals case of *R v. Harris and others*.²⁰⁴

In 2013, Huyghe and Chan made a direct comparison between expert witness law in the United Kingdom and United States respectively. Concepts such as “purpose behind the use of expert witnesses”, “qualifications of expert witnesses”, and “the admissibility of evidence” were found to be similar with regard to their interpretation in the two legal frameworks.²⁰⁵ In spite of the similarities, the authors found three notable differences with regard to “conduct of expert witness”, “deposition of expert evidence”, and “admission of ultimate issues”.

²⁰⁴ *R. v. Harris and Others*, [2006] 1 Cr App. R.5.

²⁰⁵ Huyghe S and Chan A “The Evolution of Expert Witness Law under UK and US Jurisdictions” 2014 *JAMS Global Construction Solutions*. Also see, *FRE 702* and *R. v. Turner*, [1975] 1 All ER 70, and *Lord Mansfield, Folkes v. Chadd* (1782) 3 Doug 157.

They concluded that regardless of the differences, the intensity of expert testimony in both jurisdictions is similar and experts are generally held to the highest conduct.

In October 2014, Lord Chief Justice issued a “Practice Direction”²⁰⁶ admissibility test for expert evidence in courts of England and Wales. The Practice Direction test was derived from *Daubert* and was desperately needed, according to Lord Thomas.²⁰⁷ It advises judges that, as a matter of common law, expert evidence must have a sufficient reliable scientific basis to be admitted. Lord Thomas stated that “[d]espite the use of the word scientific, any common-law power must also apply to non-scientific expert evidence, as did the Law Commission’s proposals.”²⁰⁸

The Practice Direction differs from *Daubert* in focusing less on whether a body of expertise qualifies as knowledge, and more on the permissible strength of particular inferences drawn from that body of knowledge or experience. It protects the jury against the dangers of undue deference while also preserving its role as arbiter of the weight of expert evidence.²⁰⁹

3.3.3 South Africa

3.3.3.1 The expert opinion

The English law played a key role in the development of the legal system in South Africa during the 1600’s to early 1700’s.²¹⁰ Both litigation and court procedures changed throughout this time. In 1715, the law changed to the Roman-Dutch law,²¹¹ but with the British invasion in 1828 it reverted

²⁰⁶ Ministry of Justice, Practice Direction 32-Evidence, Supplements CRP Part 32, 2014-10-07.

²⁰⁷ Thomas of Cwmgiedd, Lord CJ 2014a. *Practice Direction (Criminal Proceedings: Various Changes)*. <http://www.judiciary.gov.uk/wp-content/uploads/2014/07/Criminal-Practice-Directions-Amendment-No.2.pdf>. (Date of use: 10 December 2019). See also: Thomas of Cwmgiedd, Lord, CJ 2014b. “*The Future of Forensic Science in Criminal Trials*” <http://www.judiciary.gov.uk/wp-content/uploads/2014/10/kalisher-lecture-expert-evidenceoct-14.pdf>. (Date of use: 10 December 2019).

²⁰⁸ Thomas “Future of forensic science” 2014b.

²⁰⁹ Ward T “An English Daubert? Law, Forensic Science and Epistemic Deference” 2015 *J of Phil Sci and Law: Daubert Special* 15(29):26-36.

²¹⁰ Knoetze. 2014.22

²¹¹ Visagie GG “*Die regsbedeling aan die Kaap onder die V.O.C.*” 1963 *Acta Juridica* 118-153. The collected edition of the Statutes of Batavia of 1642 seems to have been promulgated at the Cape in 1715, pointing to the adoption of Roman-Dutch law at this time.

to British law with Ordinance 41 of 1828 (and the introduction of a jury system). De Vos²¹² is of the opinion that the introduction of the jury system and the imposed artificial and unrealistic English system of litigation did not improve the South African legal system. Expert testimony took place behind closed doors and commissioners would convey the testimony to the court. No cross-examination was allowed by any party but the commissioner. Whichever party called the witness had to provide the commissioner with an affidavit of the expert witness containing a list of questions to be asked to the witness. These questions would then serve as shortcomings on the expert report as a form of cross-examination. The testimony of the expert would then be recorded in the court and became *in forma probanti*.²¹³ The first known record of the admissibility of expert witnesses in South Africa dates back to 1896, in the decision of *Marais v Smuts*,²¹⁴ where Judge Gregorowski referred to experts and their testimony in the following manner:

“Their opinion is grounded on certain experiences and study which they have given to the question; they are therefore in a better position than the Court, which has to decide the question.”

On 31 May 1910 the Union of South Africa was established in accordance of the South African Act 1909,²¹⁵ with its independence from British Parliament.²¹⁶

In 1915 in one of the first rulings under the Union in *Fullard v de Witt*,²¹⁷ the use of expert testimony was criticised for the first time. Appellate Judge Kotze remarked as follows with regard to an expert’s opinion:

“I think it should be received with caution, and that its value, if any, must necessarily depend upon the reasons which the experts give for their opinion, and must be regarded in connection with the other proved factors in the particular case.”²¹⁸

²¹² De Vos W Le R, 1992:247, Die rol van die hof en die partye in die Engelse en Franse siviele proses. *Tydskrif vir Suid-Afrikaanse Reg* 2:216-231.

²¹³ Anonymous *The Roman-Dutch law* 1902 South African 373.

²¹⁴ *Marais v Smuts* 1895 3 Off Rep 158.

²¹⁵ South African Act 1909 http://en.wikisource.org/wiki/South_Africa_Act_1909 (Date of use: 5 February 2020).

²¹⁶ De Vos 1992:255.

²¹⁷ *Fullard v de Wit* 1915 (1) SA 115 KPA.

²¹⁸ *Fullard v de Wit* 1915 [120].

In 1924 Judge Kotze followed up on his previous remarks in the case of *Kunz v Swart and others*, by observing that:²¹⁹

“I had occasion to deal with this matter, and I see no reason for departing from what was then said by me. The Civil law, as well as our own law, allows expert evidence as to handwriting, but in both systems the jurists regard the practice of comparison of handwriting with suspicion.”

In the case of *Hills v Hills*,²²⁰ the importance of expert testimony was reconfirmed when the judge in the case emphasised the importance of examination and cross-examination of expert witnesses before the court. Judge Millin, in *R v Jacobs*,²²¹ alluded to the importance of the justification for an expert's reasons that should be provided before the expert testimony is admitted by the court.²²² In the same judgment, Judge Ramsbottom stated that expert witnesses are not the judges of facts and that the latter responsibility will always be that of the court.

The Appeal court's judgment in *Annama v Chetty and Others*²²³ confirmed that the expert's opinion should be explained before acceptance in court. The judge emphasised that in the case of handwriting, a layman would be able to see the differences and agreements in comparisons if their attention is drawn to it and conclusions can be made. In the case of fingerprint comparisons, however, it would not be the case, because this would require specialised knowledge and experience.

In 1947 in the case of *R v Morela*,²²⁴ Judge Tindall reiterated the need for courts to not just accept opinions from experts unless the opinion was explained properly. In this case, three murder

²¹⁹ *Kunz v Swart and Others* 1924 SA 618 A:682.

²²⁰ *Hills v Hills* (II) 1933 NPD 293:294.

²²¹ *R v Jacobs* 1940 SA 142 TPD. The appellant was accused of reckless driving under the influence of alcohol causing a serious accident. The practitioner was a medical examiner who took the blood sample and determined the injuries of the accused.

²²² *R v Jacobs* 1940 SA 142 TPD: 146-147 - In cases of this sort it is of great importance that the value of the opinion should be capable of being tested; and unless the expert witness states the grounds upon which he bases his opinion it is not possible to test its correctness, so as to form a proper judgment upon it.

²²³ *Annama v Chetty and Others* 1946 AD 142.

²²⁴ *R v Morela* 1947 (3) SA 147 A:153.

suspects were apprehended for the murder of an elderly man. The expert lifted prints from the crime scene and found ten points of agreement in the prints to those of one of the suspects. The court required the expert to testify in the case and explain all the points of agreement.

In *Ruto Flour Mills Ltd. V Adelson*,²²⁵ Judge Boshoff pointed out that the relevance of the expert's competency is of minor importance and the focus should rather be on the relevance of the evidence. In 1964 in *R v Bunniss*,²²⁶ it was concluded that the crucial factor of expert testimony does not lie in how the expert obtained the skill, but rather that they do possess the skill.

The question of whether the court failed to judge the admissibility of the fingerprint expert's testimony,²²⁷ was raised in 1965 in the case of *S v Nala*.²²⁸ The court noted, with regard to the role of the expert during trial, that the objective was not to convince itself that there were enough points of agreement between the latent print and the known print, but whether the expert's opinion on the identity of the fingerprint in question could be supported.²²⁹

3.3.3.2 Legislation on expert testimony and admissibility

In 1917, the Criminal Procedure and Evidence Act (Kriminele Procedure en Bewijslevering 31 van 1917²³⁰) was codified and later replaced by the Criminal Procedure Act 56 of 1955.²³¹

²²⁵ *Ruto Flour Mills Ltd. v Adelson* 1958 (4) SA 235 TPD. Nowadays, however, it is relevance and not competency that is the main consideration. Generally speaking, all evidence that is relevant to an issue, is admissible, while all that is irrelevant is excluded.

²²⁶ *R v Bunniss* 1964 50 W.W.R 422 - It simply endeavours to save time and avoid confusing testimony by telling the witness: the tribunal is on this subject in possession of the same materials as yourself; thus, as you can add nothing to our materials for judgment, your further testimony is unnecessary, and merely cumbers the proceedings.

²²⁷ *S v Nala* 1965 (4) SA 360 A:361B.

²²⁸ *S v Nala* 1965 (4) SA 360 A

²²⁹ *S v Nala* 1965 (4) SA 360 A:362E.

²³⁰ Schmidt CWH and Rademeyer H "*Bewysreg*" (Durban: LexisNexis Butterworths 4th ed 2006) 13.

²³¹ Schmidt *Bewysreg* 2006 [13]. Also, Zeffert DT *et al.* "The South African law of evidence" (Durban: Lexis Nexis Butterworths 2003) 8 – Die Strafproseswet 56 van 1955 is op sy beurt vervang deur die Strafproseswet 51 van 1977. Translated to (The Criminal Procedure Act 56 of 1955 was in turn replaced by the Criminal Procedure Act 51 of 1977).

In 1977, the Criminal Procedure Act 56 of 1955 was replaced by the Criminal Procedure Act, 1977 (Act 51 of 1977).²³² This act is currently in force and has specific provisions relating to expert testimony and admissibility, captured below in table 3.3.

Table 3.3: Criminal Procedure Act 56 of 1955: Chapter 24: Evidence²³³

Section	Description	Points of interest
208	Conviction may follow on evidence of single witness	An accused may be convicted of any offence on the single evidence of any competent witness.
209	Conviction may follow on confession by accused	An accused may be convicted of any offence on the single evidence of a confession by such accused that he committed the offence in question
212	Proof of certain facts by affidavit or certificate	Affidavit must contain: 1(a) Person is in the service of the State 4(a) Whenever any fact established by any examination or process requiring any skill— (i) in biology, chemistry, physics, astronomy, geography or geology; (ii) in mathematics, applied mathematics or mathematical statistics or in the analysis of statistics; (iii) in computer science or in any discipline of engineering; (iv) in anatomy or in human behavioral sciences; (v) in biochemistry, in metallurgy, in microscopy, in any branch of pathology or in toxicology; or (vi) in ballistics, in the identification of fingerprints or body-prints or in the examination of disputed documents, 8(a) In criminal proceedings in which the collection, receipt, custody, packing, marking, delivery or dispatch of any fingerprint or body-print, article of clothing, specimen, bodily sample, crime scene sample, tissue (as defined in section 1

²³² Parliament of South Africa, Criminal procedure Act, Act 51 of 1977, 22 July 1977.

²³³ Criminal procedure Act 1977, Acts on-line, https://www.acts.co.za/iframe/criminal-procedure-act-1977/criminal_procedure_act_1977_a (Date of use: 10 December 2019).

		<p>of the National Health Act), or any object of whatever nature is relevant to the issue, a document purporting to be an affidavit made by a person who in that affidavit alleges—</p> <p>(i) that he or she is in the service of the State or of a provincial administration, any university in the Republic or anybody designated by the Minister under subsection (4);</p> <p>(ii) that he or she in the performance of his or her official duties—</p> <p>(aa) received from any person, institute, State department or body specified in the affidavit, a fingerprint or body-print, article of clothing, specimen, bodily sample, crime scene sample, tissue or object described in the affidavit, which was packed or marked or, as the case may be, which he or she packed or marked in the manner described in the affidavit;</p> <p>(bb) delivered or dispatched to any person, institute, State department or body specified in the affidavit, a fingerprint or body-print, article of clothing, specimen, bodily sample, crime scene sample, tissue or object described in the affidavit, which was packed or marked or, as the case may be, which he or she packed or marked in the manner described in the affidavit;</p> <p>(cc) during a period specified in the affidavit, had a fingerprint or body-print, article of clothing, specimen, bodily sample, crime scene sample, tissue or object described in the affidavit in his or her custody in the manner described in the affidavit, which was packed or marked in the manner described in the affidavit,</p>
212A	Proof of certain facts by affidavit from person in foreign country	The admissibility and evidentiary value of an affidavit contemplated in subsection (1) shall not be affected by the fact that the form of the oath, confirmation or attestation thereof differs from the form of the oath, confirmation or attestation prescribed in the Republic.

		<p>A court before which an affidavit contemplated in subsection (1) is placed, may, in order to clarify obscurities in the said affidavit, at the request of a party to the proceedings order that a supplementary affidavit be submitted or that oral evidence be heard: Provided that oral evidence shall only be heard if the court is of the opinion that it is in the interests of the administration of justice and that a party to the proceedings would be materially prejudiced should oral evidence not be heard.</p>
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It is important to note that in section 212, a distinction is made between those experts with skills in the sciences and those with skills in patterned evidence examination (ballistics and fingerprints).

Other than the *Federal Rules of Evidence* and *Daubert* requirements, set in the United States, it is not a *sine qua non* that an expert requires theoretical training and possesses practical expertise.²³⁴ This is also accordance with the United States' Supreme Court ruling of *Kumho Tire Co. v. Carmichael*, discussed in paragraph 3.1.4 above. This important requirement was also emphasised by South African judges.

For example, Judge Addleson noted in his ruling in *Menday v Protea Assurance*²³⁵ that:

“However eminent an expert may be in a general field, he does not constitute an expert in a particular sphere unless by special study or experience he is qualified to express an opinion on that topic. The dangers of holding otherwise – of being overawed by a recital of degrees and diplomas – are obvious: the court has then no way of being satisfied that it is not being blinded by pure ‘theory’ untested by knowledge or practice. The expert must either himself have knowledge or experience in the special field on which he testifies (whatever general knowledge he may also have in pure theory) or he must rely on knowledge or experience of experts other than themselves who are shown to be acceptable experts in that field.”

²³⁴ Carr CJ and Beaumont SJ *Law of evidence* (London: Blackstone Press 3rd ed 1992). So long as a witness satisfies the court that he is skilled, the way in which he acquired his skill is immaterial. The test of expertness, so far as the law of evidence is concerned, is skill, and skill alone, in the field in which it is sought to have the witness's opinion.

²³⁵ *Menday v Protea Assurance Co (Pty) Ltd* 1976 (1) SA 565 (E).

In *S v Veldhuizen*,²³⁶ the Court considered the meaning of *prima facie* proof in section 212 of the Act and remarked as follows:

"The words "prima facie evidence" cannot be brushed aside or minimized. As used in this section they mean that the judicial officer will accept the evidence as prima facie proof of the issue and, in the absence of other credible evidence, that prima facie proof will become conclusive proof."

In the 1983 case of *R v Silverlock*,²³⁷ a person who practiced handwriting examinations as a hobby for many years, was considered an expert in court although he had no qualifications or training. Professional qualifications do have an influence in some cases, according to Reynolds and King.²³⁸ They state that the courts do take note of factors such as firsthand knowledge of events that happened, the magnitude of experience, the stature of the expert in the relevant field, and the value of the evidence. It is however the level of qualifications that gives credibility to an expert's trustworthiness and honesty. For Keane,²³⁹ the expert has three main purposes to the court, namely the expert as:

- advisor;
- the expert's role in preparation of the trial; and
- the expert's role during the trial.

²³⁶ *S v Veldhuizen* 1982(3) SA 413 AD, 416G-H.

²³⁷ *R v Silverlock* 1894 (2) QB 766. Also, Kenny A "The expert in court" 1983 *The Law Quarterly Rev* 99: 197-216.

²³⁸ Reynolds PM and King PSD *The expert witness and his evidence* (Oxford: Blackwell Scientific Publications 2nd ed 1992).

²³⁹ Keane A *The modern law of evidence* (London: Butterworths 2nd ed 1989).

In *Mkhize v Lourens and Another*,²⁴⁰ rules 36(9)(a) and (b) of the High Court Rules²⁴¹ were raised with regard to an expert's qualifications that were not on record and the defence argued that the expert's opinion should be disregarded. Judge Webster made the following statement:²⁴²

"It is my considered view that the objection to Shedden's evidence is well taken. The Rule 36(9)(a) and (b) notice and summary of the evidence to be given by an expert at trial have no evidential value. Their purpose is to apprise the opposition of these facts so that proper and timeous preparation can be made to meet such evidence and to challenge it if it is necessary to do so. A party does not waive his right to object to evidence given by someone who is described as an expert if there are reasons for doing so. The court has to be satisfied that such witness does indeed possess expert and specialized knowledge which the Court does not know or can take judicial cognisance of. The failure to have Shedden's qualifications and alleged expert knowledge established was accordingly a fatal flaw. His evidence remains mere opinion evidence that is irrelevant. This flaw, however, is a highly technical one."

In 2001 in *Michael v Linksfeld Park Clinic*, the judge noted that the value of the expert opinion should depend on his/her qualifications, skills and experience.²⁴³ Appellate Judge Howie concluded in his remarks that expert testimony should be addressed in a different mindset as it has been done by the High court. He stated the following:²⁴⁴

"However, it is perhaps as well to re-emphasize that the question of reasonableness and negligence is one for the Court itself to determine on the basis of the various, and often conflicting, expert opinions presented. As a rule, that determination will not involve considerations of credibility but rather the examination of the opinions and the analysis of their essential reasoning, preparatory to the Court's reaching its own conclusion on the issues raised. What is required in the evaluation of such evidence is to determine whether and to what extent their opinions advanced are founded on logical reasoning."

²⁴⁰ *Mkhize v Lourens and Another* 2003 (3) SA 292 TPD.

²⁴¹ Department of Justice, Rules regulating the conduct of the proceedings of the several provincial and local divisions of the High Court of South Africa, Legislation updated to: 26 June 2009. [https://www.justice.gov.za/legislation/rules/UniformRulesCourt\[26jun2009\].pdf](https://www.justice.gov.za/legislation/rules/UniformRulesCourt[26jun2009].pdf) (Date of use: 2 February 2020).

²⁴² *Mkhize* 2003 [299B-E].

²⁴³ Carstens P and Pearmain D *Foundational Principles of South African Medical Law* (Durban: LexisNexis 2002) 430.

²⁴⁴ *Michael and Another v Linksfeld Park Clinic (Pty) Ltd and Another* 2001 (3) SA 1188 A: 1200.

An expert witness, unless he has an objection to taking the oath, shall be examined under oath.²⁴⁵ A failure to administer the oath will result in the "evidence" being inadmissible.²⁴⁶ Informed by the British common law of evidence, a witness in South Africa can as a general rule not testify in court by merely reading out his written statement, confirming it and handing it in.²⁴⁷

There are certain statutory exceptions to the general rule that a witness should give oral evidence. Section 212(4)(a) of the Criminal Procedure Act makes provision for the use of affidavits and certificates as a means of adducing expert evidence. The mere production of such an affidavit or certificate will constitute *prima facie proof* of the facts contained therein.²⁴⁸ Since 1 September 1997, an affidavit or certificate containing an opinion will also constitute *prima facie proof* of that opinion, if both the expertise and the grounds for the opinion can be ascertained from the affidavit or certificate. Where an objection has been made by any counsel, the statement will be inadmissible.²⁴⁹

In *S v Raingobin*,²⁵⁰ Milne explained that expert reports are frequently handed in as exhibits, but emphasised that these are not, however, the evidence. The evidence is the oral evidence given by the expert, and the notes are merely an *aide-memoire*.²⁵¹

The role of the expert in the South African courts is to fulfill the requirements of an assistant to the court. The needs of the client is subservient to this function.²⁵²

²⁴⁵ Act 51 of 1977, S 162.

²⁴⁶ *S v Naidoo* 1962 2 SA 625 (A).

²⁴⁷ *S v Molefe* 1975 3 SA 495 (T); *S v Mbatha* 1965 1 SA 560 (N).

²⁴⁸ The meaning of *prima facie* proof was explained in *S v Veldthuisen* 1982 3 SA 413 (A) 416 by *Diemont JA* "[*Prima facie* evidence means] that the judicial officer will accept the evidence as *prima facie* proof of the issue and, in the absence of other credible evidence, that evidence will become conclusive proof."

²⁴⁹ Act 51 of 1977, S 213(2)(d).

²⁵⁰ *S v Raingobin*, 1986 4 SA 117 (N).

²⁵¹ *S v Ramgobin* [146].

²⁵² *Meintjes-Van der Walt* 2003(b):46 - This approach makes it clear that despite the general adversarial tradition followed in South Africa, an expert owes allegiance to the court and not to the party on whose behalf he has been called.

Section 212 of the Criminal Procedure Act provides for the proof of a wide range of facts, primarily within the domain of expert evidence, by way of affidavits or certificates, which would create *prima facie* proof of the contents thereof). This has become known as “section 212 affidavits”. In the case of *State v Sithole*, the defence challenged the 212 affidavit and requested the state witness to testify in court. Judge Bam comment in this regard was as follows:

“In our law it is every person’s constitutional right to challenge evidence against him or her in a court of law. Section 35(3)(i) of the Constitution, Act 108 of 1996, reads as follows: “Every accused person has a right to a fair trial, which includes the right -(i) to adduce and challenge evidence.”

3.3.4 *Australia*

Australian law has experienced similar challenges when it came to expert evidence and admissibility thereof in the court. One case of interest was that of Colin Ross. On December 30th, 1921 a 13-year old girl, Alma Tirtschke, was reported missing in Melbourne Australia. Soon after a nearby bar owner, Colin Ross, was charged with the rape and murder of Alma. It was first based on hearsay evidence, but authorities knew they needed physical evidence. They discovered hair similar to the murdered girl’s on a blanket in Ross’s house. In 1922, a forensic expert, Charles Price, examined and identified the hair as human hair. He also compared the hair to control samples of the victim. He also indicated that hair follicles (hair roots) were present indicating a struggle. This case is known as the first time that forensic evidence was admitted in an Australian court. The defence put the expert to the test in the court by providing various hair samples to the expert for comparison. The exercise backfired as the expert matched all the samples to the correct known ones and Ross was found guilty and hanged.²⁵³ Recent research, however, has demonstrated that the hair samples were misidentified and that Ross might have been innocent. On 23 October 2006, the Victorian Attorney General Rob Hulls wrote to the Chief Justice, Marilyn Warren, with a 31-page petition asking her to consider a plea of mercy for Ross. The subsequent

²⁵³ Rea A “Homicide: Alma Tirtschke” 2016-06-26 *National Library of Australia*.

pardon, granted on 27 May 2008, is the first case in Victoria's legal history of a posthumous pardon.²⁵⁴

3.3.4.1 Legislation on expert evidence

Australia has a complicated system with many challenges. The national government (the Commonwealth) and six States shared the powers under this system. The Constitution defines the boundaries of law-making powers between the Commonwealth and the States/Territories. There are also three self-governing territories - Australian Capital Territory, Northern Territory, and Norfolk Island in addition to the six States (New South Wales, Queensland, South Australia, Tasmania, Victoria and Western Australia).

The legal system, a common law system, was inherited from England at the time of colonialisation. Like many legal systems, the laws of evidence prescribe standards to which a fact must be proved: in civil proceedings, facts must be proved on the balance of probabilities; and in criminal proceedings, facts must be proved beyond reasonable doubt. The rules of evidence govern what information is able to be placed before a court for determination of an issue. These rules influence how a party prepares proving its case. Counsels seek ways to persuade the court of a fact by producing evidence. Historically, attorneys considered three issues: how to adduce evidence of the fact; whether the evidence is admissible, and the weight of the evidence. The rules of evidence primarily focus on the first two issues: how information, in the form of "evidence", is given or presented to a court; and whether that information can be admitted to the proceeding.

The admissibility of evidence in any proceeding is subject to compliance with the rules of admissibility and the interpretation placed upon them by the presiding judge. Assessment of the quality of evidence, and therefore of the weight to be given to it, is also matter for the presiding judge in each case.

²⁵⁴ Cowan J "Colin Campbell Ross: Murderer Murderpedia, male murderers" *The World Today*, 1921. <http://murderpedia.org/male.R/r/ross-colin-campbell.htm> (Date of use: 11 December 2019).

There are significant differences in the Australian law and the rules for expert evidence across the nine States, Territories and Commonwealth jurisdictions. Some jurisdictions have Uniform Evidence Acts, whilst the common law of evidence still applies in three jurisdictions. Some jurisdictions have explicit codes of conduct for expert witness testimony, while others do not. Similar rules that regulate expert witness testimony in civil procedures exist. The challenge that experts are facing is that the expert evidence that is complying in one jurisdiction may not necessarily comply with the rules in another jurisdiction. Parties wanting to use expert evidence and expert witnesses in a Federal proceeding should be familiar with the Evidence Act 1995 (including Part 3.3) and Part 23 of the Federal Court Rules 2011 (Rules).²⁵⁵

The Federal Court has also issued a number of practice notes which provide guidance on the use of expert evidence:

- Expert Evidence Practice Note (GPN-EXPT), which includes the Code of Conduct for Expert Witnesses and Guidelines for concurrent expert evidence²⁵⁶
- Central Practice Note (CPN-1)²⁵⁷
- Survey Evidence Practice Note (GPN-SURV).²⁵⁸

There are differences in the applicable evidence law between Australian jurisdictions. The Commonwealth, Australian Capital Territory, New South Wales, Northern Territory, Norfolk Island, Tasmania and Victoria are known as the Uniform Evidence Act jurisdictions, whereas the common law still applies in Queensland, South Australia and Western Australia.

²⁵⁵ Charrett D “*The rules for expert evidence in Australia*” Melbourne TEC Chambers <https://mtecc.com.au/the-rules-for-expert-evidence-in-australia/> (Date of use: 11 December 2019).

²⁵⁶ Federal Court of Australia “*Expert Evidence Practice Note (GPN-EXPT)*” 25 October 2016. <http://www.fedcourt.gov.au/law-and-practice/practice-documents/practice-notes/gpn-expt> (Date of use: 11 December 2019).

²⁵⁷ Federal Court of Australia “*Central Practice Note: National Court Framework and Case Management (CPN-1)*” 25 October 2016. <http://www.fedcourt.gov.au/law-and-practice/practice-documents/practice-notes/cpn-1> (Date of use: 11 December 2019).

²⁵⁸ Federal Court of Australia “*Survey Evidence Practice Note (GPN-SURV)*” 25 October 2016. <http://www.fedcourt.gov.au/law-and-practice/practice-documents/practice-notes/gpn-surv> (Date of use: 11 December 2019).

One notable example of a difference between the common law and the Uniform Evidence Act is the issue of when an expert's draft reports can be called for or disclosed, as was set out by Judge Dodds-Streeton in the case of *Shea vs. TruEnergy Services Pty Ltd*.²⁵⁹

Each Australian jurisdiction has rules that govern the content of, and the manner of giving expert evidence. The provisions of Reg. 31.17 of the Uniform Civil Procedure Rules 2005 (NSW) are typical of the rationale for these rules.²⁶⁰ The objective of these provisions are:

- (a) to ensure that the court has control over the giving of expert evidence;
- (b) to restrict expert evidence in proceedings to that which is reasonably required to resolve the proceedings;
- (c) to avoid unnecessary costs associated with parties to proceedings retaining different experts;
- (d) if it is practicable to do so without compromising the interests of justice, to enable expert evidence to be given on an issue in proceedings by a single expert engaged by the parties or appointed by the court;
- (e) if it is necessary to do so to ensure a fair trial of proceedings, to allow for more than one expert (but no more than are necessary) to give evidence on an issue in the proceedings; and
- (f) to declare the duty of an expert witness in relation to the court and the parties to proceedings.

It is the specific scope and content of the rules applicable to expert evidence that differ significantly between Australian jurisdictions. One common feature of the different rules and codes of conduct is that the court exercises considerable control over the form of expert evidence. This is reflective of the importance of, and the need for the court to rely on expert opinion in many cases. Such reliance is only possible if expert reports comply with appropriate procedures for the preparation and articulation of expert evidence. Legal practitioners and experts involved in the preparation and

²⁵⁹ *Shea vs. TruEnergy Services Pty Ltd* (No 5) [2013] FCA.

²⁶⁰ There is a similar statement of purposes in section 1200 of Court Procedures Rules 2006 (ACT).

presentation of expert evidence in a particular jurisdiction must be familiar with and comply with the relevant rules.

A number of years ago, the Expert Subcommittee of the Society of Construction Law Australia prepared a detailed comparison of the rules and codes of conduct applying to expert evidence in the various courts of the different Australian jurisdictions. Table 3.4 below summarises the location of the applicable rules and codes of conduct in those nine Australian superior court jurisdictions:²⁶¹

Table 3.4: Codes of conduct in Australian jurisdictions

Jurisdiction and evidence law	Evidence Act	Civil Procedure Rules relating to expert evidence	Expert Witness Code of Conduct
Supreme Court of the Australian Capital Territory (ACT)	Uniform Evidence Act Evidence Act 2011 (ACT)	Court Procedures Rules 2006 (ACT) Part 2.12 Expert Evidence Rules 1200—1246	Schedule 1 Expert Witness Code of Conduct
Federal Court of Australia (FCA)	Uniform Evidence Act Evidence Act 1995	Federal Court Rules 2011 (Cth) Rule 5.04 and Part 23 Experts RR 23.01—23.15	Practice Note CM7 Expert Witnesses in proceedings in the Federal Court of Australia
Supreme Court of New South Wales (NSW)	Uniform Evidence Act Evidence Act 1995 (NSW)	Uniform Civil Procedure Rules 2005 (NSW) Rules 31.17—31.54	Schedule 7 Expert Witness Code of Conduct
Supreme Court of the Northern Territory (NT)	Uniform Evidence Act Evidence Act 2011 (NT)	Supreme Court Rules (NT) Order 44 Expert Evidence	—
Supreme Court of Queensland (Qld)	Common law Evidence Act 1977 (Qld)	Uniform Civil Procedure Rules 1999 (Qld) Ch 11, Part 5, Division 2 Rules 423—429S	—
Supreme Court of South Australia (SA)	Common law Evidence Act 1929 (SA)	Supreme Court Civil Rules 2006 (SA) Rules 160, 161	Part I Practice Direction 5.4 Expert Witnesses (Rule 160)
Supreme Court of Tasmania (Tas)	Uniform Evidence Act Evidence Act 2001 (Tas)	Supreme Court Rules 2000 (Tas) Part 19 Division 5 Expert Opinion Evidence Rules 514—517	—

²⁶¹ Charrett D *Rules of expert evidence*.

Supreme Court of Victoria (Vic)	Uniform Evidence Act Evidence Act 2008 (Vic)	Supreme Court Rules 2005 (Vic) Order 44 Expert Evidence Rules 44.01—44.06	Form 44A Expert Witness Code of Conduct
Supreme Court of Western Australia (WA)	Common law Evidence Act 1906 (WA)	Rules of the Supreme Court 1971 (WA) Order 36A Expert Evidence Rules 1—9	—

3.3.4.2 Expert Reports and code of conduct

In jurisdictions that have an expert witness code of conduct, an expert is bound by its provisions, and has to acknowledge in their report that s/he has read, understood and complied with the code.

The importance of this formal acknowledgement is highlighted by the provision in the ACTSC rules:

“If an expert report does not contain an acknowledgement by the expert witness who prepared the report that the expert witness has read the code of conduct and agrees to be bound by it, service of the expert report by the party who engaged the expert is not valid service.”²⁶²

The rules in three jurisdictions specify whether the expert evidence code/rules apply to a party who is also qualified to act as an expert witness. The expert witness code of conduct does not apply in Victoria,²⁶³ nor do the Rules apply in Queensland,²⁶⁴ however, the Practice Direction applies to a party witness in South Australia.²⁶⁵

Expert witnesses have some or all of the following obligations in the majority of jurisdictions:

- Overriding duty to assist the court
- Paramount duty is to the court
- An expert witness is not an advocate for a party
- A duty to comply with court directions or cooperate with another expert witness.²⁶⁶

²⁶² ACT Government, Court Procedures Rules 2006 (ACT) R1203(3), SL2006-29 Under Court Procedures Act 2004, s7, current version 2019-09-24.

²⁶³ Supreme Court Rules 2005 (Vic) R44.02(2), Version No. 050, 11 October 2013.

²⁶⁴ Supreme Court of Queensland Act 1991, Uniform Civil Procedure Rules 1999 (Qld) R424, 1 March 2017.

²⁶⁵ Supreme Court Civil Rules 2006, Practice Direction 5.4 Expert Witnesses 5.4.8, 4 September 2006.

²⁶⁶ Australian Council of Professions “*Role and Duties of an Expert Witness*” <http://www.professions.com.au/advocacy/archives/item/role-and-duties-of-an-expert-witness> (Date of use: 2 February 2020).

All jurisdictions define in the Rules and/or Codes of Conduct, some of the following procedural requirements:

- A party is required to give an expert witness a copy of the code of conduct.
- Expert is to issue a supplementary report when they have changed their opinion for any reason.
- Notice to the court where an expert has changed their opinion.
- Draft of expert report communicated to a party is to be retained by an expert.²⁶⁷

In respect of the service of expert reports, the wording in the rules is significantly different between jurisdictions. Reports are to be served according to rules per jurisdiction:

- ACTSC: 'each expert report obtained by the party in accordance with any direction made by the court';²⁶⁸
- FCA: 'an expert report that complies with rule 23.13';²⁶⁹
- NSWSC: 'experts' reports';²⁷⁰
- NTSC: 'a statement in accordance with sub-rule (2)';²⁷¹
- QSC: a report that a party is intending to rely on;²⁷²
- SASC: 'a copy of each expert report in the party's possession relevant to the subject matter of an action (whether the party intends to rely on it at the trial or not)';²⁷³
- TSC: 'a statement signed by the witness' where a party intends to adduce oral evidence from the expert witness at trial;²⁷⁴

²⁶⁷ Federal Court of Australia "*Expert Evidence & Expert Witnesses*" Evidence Act 1995 (including Part 3.3) and Part 23 of the Federal Court Rules 2011 (Rules). <https://www.fedcourt.gov.au/law-and-practice/guides/expert-evidence> (Date of use: 2 February 2020).

²⁶⁸ Court Procedures Rules 2006 (ACT) R1240.

²⁶⁹ Federal Court Rules 2011 (Cth) R23.11.

²⁷⁰ Uniform Civil Procedure Rules 2005 (NSW) R31.28.

²⁷¹ Supreme Court Rules (NT) R44.03.

²⁷² Uniform Civil Procedure Rules 1999 (Qld) R429.

²⁷³ Supreme Court Civil Rules 2006 (SA) R160.

²⁷⁴ Supreme Court Rules 2000 (TAS) R516 (2).

- VSC: 'a report by the expert', where 'a party who intends at trial to adduce the evidence of a person as an expert';²⁷⁵
- WASC: 'a report of an expert witness the substance of which a party intends to rely on at the trial or hearing'.²⁷⁶

South Australia is thus the only jurisdiction that requires that all expert reports in a council's possession to be distributed to every other party, whether or not the council intends to rely on these reports at trial or not. South Australia is also the only jurisdiction that explicitly requires an expert witness to retain a copy of any draft report s/he has communicated to a council.²⁷⁷

Western Australia is the only jurisdiction that does not specify some or all of the following requirements for the content of an expert report:²⁷⁸

- Contents of expert report.
- Statement that expert has understood and complied with their duty.
- Statement that expert has made all inquiries that they believe appropriate.
- Summary of expert's qualifications and experience.
- Statement that opinion is provisional when available information is insufficient.
- Statement that opinion is qualified when available information is incomplete or inaccurate.
- Statement that a particular question or issue is outside the expert's expertise.
- Statement that opinion is genuinely held by the expert.
- Acknowledgement that opinions are based on the expert's specialised knowledge.
- Report to be signed by the expert.
- Details of the expert's fees or communications with the expert.

²⁷⁵ Supreme Court (General Civil Procedure) Rules 2005 (Vic) R44.03 (1).

²⁷⁶ Rules of the Supreme Court 1971 (WA) R36A. 3 (4).

²⁷⁷ Practice Direction 5.4 Expert Witnesses 5.4.5.2.

²⁷⁸ The Law Reform Commission of Western Australia, Annual Report, 1 July 1999 – 30 June 2000.

All jurisdictions have procedural rules and/or provisions in codes of conduct in respect of pre-trial conferences between experts, with the exception of Western Australia, covering some or all of the following issues:

- Court may direct a conference with another expert.
- Court direction to produce a joint report setting out the opinions where experts agree and disagree and the reasons why they disagree.
- Experts must endeavor to reach agreement.
- Expert is not to act on any instruction to withhold or avoid agreement with other expert witnesses.

The purpose of these provisions is to minimise the differences between expert opinions that addresses the facts on which expert opinions are based, as well as ensuring that experts address the same questions. The prescribed procedures generally strive to minimise the influence of lawyers on the outcome of an experts' conference, perhaps by excluding lawyers from attending, and ensuring that the conference proceedings themselves are 'without prejudice'.

The modern focus on expert evidence is on the preparation of expert reports as evidence-in-chief, but oral testimony may still be important to supplement or test expert evidence. Procedural rules cover some or all of the following issues:

- Complying expert report is a precondition to giving oral evidence.
- Experts to consider factual evidence adduced at trial.
- Cross-examination of experts can be separate or concurrent.
- Expert permitted to question other experts.
- Expert can give an exposition of his/her own opinion or their opinion about other experts' opinions.
- How lay or expert evidence in the hearing may be given.
- The scope of evidence-in-chief is restricted.
- Expert must be available for cross-examination if required.

In majority of jurisdictions, the preparation of an abiding expert report is an obligatory condition for giving oral testimony, and an expert witness must be at hand for cross-examination if required.

Courts have broad discretion to embrace procedures for giving expert testimony appropriate to the circumstances, such as their location in the court room, the chronological order in which factual and expert testimony is given, the order of cross-examination, the ability for expert witnesses to give an explanation of their own opinion, or to question the opinion of other expert witnesses.

Five jurisdictions have a provision that expert witnesses can be required to confirm their opinions or otherwise after the factual evidence has been adduced.²⁷⁹

3.3.4.3 Admissibility of evidence

Part 15 of the Federal Magistrates Court Rules 2001 contain rules of evidence for the Federal Magistrates Court.²⁸⁰ The admission of both electronic and hard copy created documents in evidence before federal courts are provided by the Commonwealth Evidence Act.

The Commonwealth Evidence Act relaxed by removing restrictions on evidence that can be admitted in proceedings in some cases, so that a larger dimension of relevant evidence is available to courts for fact finding purposes. With a larger dimension of evidence admissible in many Australian courts, law enforcement agencies must weigh the quality of evidence available in a legal proceeding and whether that evidence is probable to persuade a court to accept the Commonwealth's version of the facts.

²⁷⁹ Court Procedures Rules 2006 (ACT) Rule 1211; Federal Court Rules 2011 (Cth) Rule 23.15; Uniform Civil Procedure Rules 2005 (NSW) Rule 31.35; Supreme Court Rules (NT) Order 44.05(2); Supreme Court Rules 2000 (Tas) Rule 516(6).

²⁸⁰ Federal Register of Legislation, Federal Magistrates Court Rules 2001, Statutory Rules 2001 No. 195 as amended, 29 March 2004.

3.3.4.4 Expert opinion and specialised knowledge

Expert witnesses are allowed to offer opinions to the court as to the significance and entailments of facts and opinions, which is different from other kinds of witnesses. The main distinction between lay and expert opinion evidence is that of the two categories of opinion evidence, only expert opinion evidence is based on 'specialised knowledge' in a sense peculiar to this branch of the law.

According to Freckelton and Selby,²⁸¹ the common law of expert opinion evidence differs between jurisdictions on the rules that control admissibility. They have formulated the following list as rules of admissibility at common law:

- *The field of expertise rule:* The claimed knowledge or expertise should be recognised as credible by others who are capable of evaluating its theoretical and experiential foundations.
- *The expertise rule:* The witness should have sufficient knowledge and experience to entitle him or her to be held out as an expert who can assist the court.
- *The common knowledge rule:* The information sought to be elicited from the expert should be something upon which the court needs the help of a third party, as opposed to relying upon its general knowledge and common sense.
- *The ultimate issue rule:* The expert's contribution should not have the effect of supplanting the function of the court in deciding the issue before it.
- *The basis rule:* The admissibility of expert opinion evidence depends on proof of the factual basis of the opinion.

These rules had been applied and tested in many degrees of rigour over the years. Some rules might have been oversimplified, but are inherently more complex. The key to expert opinion is captured in section 79 of the Uniform Evidence Act.²⁸² If an individual has specialised knowledge

²⁸¹ Freckelton IR and Selby H *Expert Evidence: Law, Practice, Procedure and Advocacy* (Law Book Co of Australia 2nd ed 2002).

²⁸² Australian Commonwealth Acts, Exception: Opinions based on specialised knowledge, Evidence Act 1995 No. 2 of 1995 - SECT 79.

based on the person's training, study or experience, the opinion rule does not apply to evidence of an opinion of that individual that is utterly or substantially based on that knowledge.

The key components of section 79 are:

- the *specialised knowledge* requirement and the related *field of expertise* requirement;
- the requirement that expert opinion evidence be based on the *training, study or experience* of the expert witness; and
- the extent of the requirement under the Uniform Evidence Acts to show that expert opinion evidence is *based on* the application of *specialised knowledge* to relevant facts or factual assumptions.

There has been a continuous argument at common law as to what extent the law should entail the affirmation of a field of expertise or acceptance of a distinct discipline or some other requirement as a state of admissibility of expert opinion in a proceeding. The Uniform Evidence Acts require the affirmation of specialised knowledge before expert witness opinion can be given in evidence.

Similar to some other jurisdictions, the field of expertise for the purposes of the common law of evidence is not resolved in Australia.²⁸³ One question brought forward in many cases in relation to various forensic evidence such as DNA profiling, finger examination, voice identification, firearm examination, and polygraph testing, is whether there is a field of expertise in relation to which an expert witness in the discipline are allowed to give opinion testimony.²⁸⁴ The one fact that remains the same globally is that expert witnesses must be qualified by training or practical experience in an area of knowledge beyond that possessed by the trier of fact, and of apparent assistance to it.²⁸⁵

²⁸³ Australian Law Reform Commission, Evidence, ALRC 26 (Interim) Vol 1 (1985) [743]; Odgers S (Uniform Evidence Law 6th ed 2004).

²⁸⁴ Freckelton "Expert evidence" 2002.

²⁸⁵ Ligertwood A *Australian Evidence* (LexisNexis Butterworth 4th ed 2004).

In the past, some courts in Australia looked to whether a body of expert knowledge has *general acceptance* (known as *Frye test*²⁸⁶ in the United States) in the relevant, usually scientific, discipline. In South Australian case law, the question is asked whether the expert knowledge is “*sufficiently organized or recognized to be accepted as a reliable body of knowledge or experience*”, which points to acceptance by the court rather than by a professional community.²⁸⁷ In the case of *R v. Johnson* in Victoria, it has been stated that:

“Provided the judge is satisfied that there is a field of expert knowledge ... it is no objection to the reception of the evidence of an expert within that field that the views which he puts forward do not command general acceptance by other experts in the field.”²⁸⁸

Australia has seen more debate on the topic of expert knowledge after the 1993 decision of the United States Supreme Court in *Daubert v. Merrell Dow Pharmaceuticals*.²⁸⁹

The focus of the *Daubert* influence was whether the acquisition of similar standards would block the admission of evidence based on “junk” science. There were two sides to the argument, those who have supported the solicitation in Australia of the *Daubert* approach as setting more rigorous admissibility standards,²⁹⁰ against those who have concluded that it would be improbable to lead to any significant refinement in the quality of scientific expert opinion evidence.²⁹¹

Frye or *Daubert* style tests in recognised forensic disciplines do not apply to specialised knowledge in the High Courts of Australia. In *HG v. The Queen*,²⁹² Gaudron J mentioned the need, at common law, for the expert’s knowledge or experience to be in an area “sufficiently organized or recognized

²⁸⁶ *Frye* 1923. See Australian cases cited in Odgers S “*Uniform Evidence Law*” (6th ed 2004).

²⁸⁷ *R vs. Bonython* (1984) 38 SASR 45, 47.

²⁸⁸ *R vs. Johnson* (1994) 75 A Crim R 522, 535.

²⁸⁹ *Daubert* 509 US 579 (US Supreme Court, 1993).

²⁹⁰ Odgers S and Richardson J “Keeping Bad Science Out of the Courtroom: Changes in American and Australian Expert Evidence Law” 1995 *University of New South Wales, Law J* 108. Also, Edmond G and Mercer D “Keeping ‘Junk’ History, Philosophy and Sociology of Science out of the Courtroom: Problems with the Reception of *Daubert v Merrell Dow Pharmaceuticals Inc.*” 1997 *University of New South Wales Law J* 48:48-100.

²⁹¹ Edmond G and Mercer D “Keeping ‘Junk’ History, Philosophy and Sociology of Science out of the Courtroom: Problems with the Reception of *Daubert v Merrell Dow Pharmaceuticals Inc.*” 1997 *University of New South Wales Law J* 48.

²⁹² *HG vs. The Queen* (1999) 197 CLR 414, [58].

to be accepted as a reliable body of knowledge or experience”.²⁹³ In her ruling, the judge said there was no reason to think that the expression “specialised knowledge” in section 79 of the Uniform Evidence Acts “gives rise to a test which is in any respect narrower or more restrictive than the position at common law, that is, there is no reason to think that section 79 imposes additional thresholds on admissibility”.²⁹⁴

A conclusion can be drawn that, while recognition may be one premises for an inference of reliability under the Uniform Evidence Acts, it seems clear that the ultimate test is reliability of the expert’s knowledge or experience in an area.²⁹⁵

3.3.4.5 A call for reform on the Evidence Act of 1995

The Attorney General of Australia requested asked the Australian Law Reform Commission (ALRC)²⁹⁶ in 2004 to examine the operation of the Evidence Act 1995 (Cth). The ALRC established a broad based expert Advisory Committee which included practitioners from government and the private profession, members of the judiciary, and academic specialists in this field. After meeting three times, the Advisory Committee published the final report and provided aid in the development of recommendations stipulated in the report. The Terms of Reference for the Inquiry directed the ALRC to have regard to a number of matters, including the desirability of achieving greater clarity and effectiveness and promoting greater harmonisation of the laws of evidence in Australia. As part of this reference, two consultation papers were published: An Issues Paper, was released by the ALRC in December 2004;²⁹⁷ and a joint Discussion Paper was jointly produced by the LRCs in July 2005.²⁹⁸ The identification of the area of specialised knowledge was highlighted as a concern by the ALRC reports, and at the possibility that it might be tested by general acceptance or similar theories. It rejected identification of the area of specialised

²⁹³ *HG vs. The Queen*, referring to *R v. Bonython* (1984) 38 SASR 45, 46–47; *Clark v. Ryan* (1960) 103 CLR 486, 491; *Murphy v. The Queen* (1989) 167 CLR 94, 111, 130; *Farrell v. The Queen* (1998) 194 CLR 286, 292–294; *Osland v. The Queen* (1998) 197 CLR 316, [53].

²⁹⁴ *HG vs. The Queen* (1999) 197 CLR 414, [58]. See also *Velevski v. The Queen* (2002) 187 ALR 233.

²⁹⁵ Odgers S *et al. Uniform Evidence Law* (6th ed Thomson Reuters 2018)

²⁹⁶ Australian Law Reform Commission *Evidence*, 1985 [743].

²⁹⁷ Australian Law Reform Commission, Review of the Uniform Evidence Act 1995 (ALRC IP 28), 2004.

²⁹⁸ Australian Law Reform Commission, Review of the Uniform Evidence Acts (ALRC DP 69), 2005.

knowledge through application of a *general acceptance* test or a *reputable body of opinion* test of reliability because this was too rigid, and would cause much useful and reliable evidence to be excluded. It was believed that this would result in jurisdictions linger behind advances in science and other knowledge gained.

The Commission noted that most stakeholders consulted were reasonably pleased with the way section 79 of the Uniform Evidence Act has been interpreted and applied.²⁹⁹ The Commission also stated that section 79 was not intended to enact a *field of expertise* test, based on *general acceptance* or similar requirements. Also, the concerns as to probative value of evidence admitted under section 79, its potential to mislead, and the cost and time that activated more stringent rules are best addressed by the discretion under section 135 for a court not to admit evidence in certain cases, and by the discretion under section 136 to limit the use which can be made of evidence by the tribunal of fact.³⁰⁰

It was suggested that an evaluation of new and developing areas of knowledge will continue to pose a challenge for the courts due to the nature of the exercise, and that adding new criteria to the Uniform Evidence Acts would not simplify the task and would introduce new uncertainties.³⁰¹

The concept of an *ad hoc* expert³⁰² was recognised at common law by the *High Court in R v. Butera*.³⁰³ Cases since the enactment of the Uniform Evidence Acts have acknowledged that section 79 is adequate to encompass *ad hoc* experts. In the case of *ACIS v. Vines*,³⁰⁴ it was held that the term “specialised knowledge” is not limited and expressly circumscribe specialised knowledge based on experience.

²⁹⁹ Australian Law Reform Commission, New South Wales Law Reform Commission and Victorian Law Reform Commission, Review of the Uniform Evidence Acts, ALRC DP 69, NSWLRC DP 47, VLRC DP (2005), [8.47] [8.50].

³⁰⁰ Australian Law Reform Commission 2005 [8.51] [8.52].

³⁰¹ Australian Law Reform Commission, 2005 [8.53]–[8.55]. Further, section 137 requires evidence adduced by the prosecutor to be excluded by the court if the probative value of the evidence is outweighed by the danger of unfair prejudice to the defendant.

³⁰² An *ad hoc* expert is a person who, while not having formal training or qualifications in a particular area of expertise, has acquired expertise based on particular experience in that area, such becoming familiar with the handwriting of another person.

³⁰³ *R v Butera* (1987) 164 CLR 180.

³⁰⁴ *ASIC v Vines* (2003) 48 ACSR 291, 294–295.

The Commission acknowledged that the approach to *ad hoc* experts could create problems in that it gives an unlimited scope to the concepts of specialised knowledge and training, study or experience.³⁰⁵

The Law Society of South Australia submitted that section 79 should be amended to replace the words “the person’s training, study or experience” with the “person’s training and experience” or, alternatively, “the person’s study and experience”, with the belief that this would limit the number of those who could be classified as *ad hoc* experts.³⁰⁶ Although the Commission agreed that the wording would limit the number of individuals who could be classified as *ad hoc* experts, they disagreed with the suggestion. The Commission argued that changing the criteria “training”, “study” and “experience” from alternative criteria to cumulative criteria would rule out the admission of opinion evidence based on specialised knowledge obtained solely through training, solely through study, and solely through experience. To do so, would render the expertise requirement of section 79 stricter than that at common law. In criminal cases, section 137 will apply to problems arising on the broad scope of the words training, study, or experience.

The Commission viewed that “admissibility of expert opinion evidence should be approached simply by reference to the provisions of the Uniform Evidence Acts. The proper approach is to follow the overall scheme of the Uniform Evidence Acts, applying the *relevance test*, followed by the *opinion rule* and its exceptions and, finally, the *discretionary provisions*.”³⁰⁷

The Issues Paper distinguished that legal professionals have developed practices to guarantee that expert opinion evidence is presented in a way that assist them in assessing whether it complies with the requirements of section 79, including by requiring lawyers of both counsels to prepare schedules indicating how each element of expert opinion is coupled to the specialised knowledge

³⁰⁵ Australian Law Reform Commission, *Review of the Evidence Act 1995*, IP 28 (2004), [6.30] citing J Anderson, J Hunter and N Williams, *The New Evidence Law: Annotations and Commentary on the Uniform Evidence Acts* (2002) [78.15].

³⁰⁶ Criminal Law Committee of the Law Society of South Australia, Submission E 35 7 March 2005.

³⁰⁷ Commonwealth Director of Public Prosecutions, Submission E 108, 16 September 2005.

of the expert witness.³⁰⁸ The grown use of such schedules³⁰⁹ was recommended in multiple consultations.³¹⁰ To promote transparency as to the foundation of expert opinion, rules of court now necessitate expert witnesses to prepare specialised reports. For example, the Federal Court's Practice Direction Guidelines for Expert Witnesses in Proceedings in the Federal Court of Australia state, among others, that:

- an expert's written report must give details of the expert's qualifications, and of the literature or other material used in making the report;
- all assumptions of fact made by the expert should be clearly and fully stated;
- the report should identify who carried out any tests or experiments upon which the expert relied in compiling the report, and state the qualifications of the person who carried out any such test or experiment;
- the expert should give reasons for each opinion;
- there should be included in or attached to the report: (i) a statement of the questions or issues that the expert was asked to address; (ii) the factual premises upon which the report proceeds; and (iii) the documents and other materials which the expert has been instructed to consider; and
- the expert should make it clear when a particular question or issue falls outside the relevant field of expertise.³¹¹

Compliance with these requirements will supply the trier of fact with criteria enabling it to evaluate the validity of the expert's opinion.

³⁰⁸ Australian Law Reform Commission, Review of the Evidence Act 1995, IP 28 (2004), [6.41].

³⁰⁹ Such schedules are sometimes referred to as 'Ellicott' schedules.

³¹⁰ Justice C Einstein, Consultation, Sydney, 6 August 2004; I Freckelton, Consultation, Melbourne, 17 March 2005; P Greenwood, Consultation, Sydney, 11 March 2005.

³¹¹ Guidelines for Expert Witnesses in Proceedings in the Federal Court of Australia 2004 (Cth) r 2. See also Supreme Court Rules 1970 (NSW), sch 11, r 5.

In order to assure that the legal tests of admissibility are addressed, lawyers should be more involved in the writing of reports by experts.³¹² In *Harrington-Smith vs. Western Australia*, Lindgren J remarked as follows:

“Lawyers should be involved in the writing of reports by experts: not, of course, in relation to the substance of the reports (in particular, in arriving at the opinions to be expressed); but in relation to their form, in order to ensure that the legal tests of admissibility are addressed. In the same vein, it is not the law that admissibility is attracted by nothing more than the writing of a report in accordance with the conventions of an expert’s particular field of scholarship. So long as the Court, in hearing and determining applications such as the present one, is bound by the rules of evidence, as the Parliament has stipulated in s 82(1) of the [Native Title Act 1992 (Cth)], the requirements of s 79 (and of s [55] as to relevance) of the Evidence Act are determinative in relation to the admissibility of expert opinion evidence.”³¹³

The Commission received an array of divergent responses regarding the involvement of lawyers in the preparation of expert reports. The dominant view is that lawyers should be involved in order to ensure that expert reports are admissible.³¹⁴ Lawyers are involved in drafting of affidavits for lay witnesses, so there is no logical reason why they should be excluded from assisting in the preparation of expert reports.³¹⁵

While some expressed concerns that this may increase the risk that expert evidence will adopt an overly partisan position,³¹⁶ this difficulty should be seen as an ethical question that could be addressed through rules of court, legal practitioners’ rules of professional conduct and expert witness codes of conduct, rather than unnecessary contact between lawyers and experts. In a submission on DP 69, the Law Society of South Australia submitted that a move to greater involvement for lawyers in the writing of expert reports “will counteract the move of the last decade

³¹² Australian Law Reform Commission, Review of the Evidence Act 1995, IP 28 (2004), [6.42] citing *Jango vs. Northern Territory of Australia* (No 2) [2004] FCA 1004, [8]–[9] (Sackville J); *Harrington-Smith vs. Western Australia* (No 2) (2003) 130 FCR 424, [19] (Lindgren J).

³¹³ *Harrington-Smith* 2003 [19] (emphasis original). See *Yarmirr vs. Northern Territory* (2001) 208 CLR 1, [84].

³¹⁴ Greenwood P, Consultation, Sydney, 11 March 2005; Department of Justice (NT), Consultation, Darwin, 31 March 2005.

³¹⁵ Donovan B, Consultation, Sydney, 21 February 2005; Victorian Law Reform Commission Roundtable, Consultation, Melbourne, 18 August 2005.

³¹⁶ ACT Bar Association, Consultation, Canberra, 9 March 2005; The Law Society of South Australia, Submission E 69, 15 September 2005.

or so to increase the independence of experts”, but, in line with what is said above, concluded that “the court rules and ethical rules should ensure that the line of independence” is not crossed’.³¹⁷

3.4 Conclusion

A wide range of issues were addressed in this chapter, ranging from procedural tests and rules that were discussed in the admissibility of evidence; admissibility of expert opinion and the relevance of evidence.

Regardless of the jurisdiction, it is submitted that the following guidelines should apply with regard to expert evidence:

An expert would gain special knowledge in a specific discipline in forensic science. The knowledge gained could come from education (by attending university in the field of natural sciences), training (conducted by crime laboratories or external training courses), or experience (by performing specialised tasks repeatedly). Over time, the individual will have more knowledge (whether educational or technical knowledge) than the average person, also referred to as the layman (who may serve on a jury in certain jurisdictions). This expert should be exposed to certain tests (utilising acceptable and reliable techniques or methods) applied within that discipline to demonstrate competence to perform any examinations within the discipline he/she has gained knowledge in. This would be in a form of proficiency or competency testing. The combination of specialised knowledge and competency should serve as a portfolio of evidence to the court (with the judge as gate keeper) that the individual would be able assist the court as a trier of fact. Whoever serves as an expert witness should be bound by a well-defined code of conduct, ensuring that the expert will not be biased, would act ethically, and would protect the profession.

The second part of the process involves the physical evidence. Physical evidence is collected after a crime was committed. Some evidence collected may not be relevant to the crime (for example semen stains from the underpants of a male suspect). It is therefore important, firstly, for the expert

³¹⁷ The Law Society of South Australia, Submission E 69, 15 September 2005.

to acknowledge the relevance of physical evidence before conducting any examinations, and secondly, for the court to admit the evidence as relevant to the fact. If the expert decides the evidence to be relevant, he/she will follow valid and reliable techniques or methods (accepted by the larger scientific community through peer-reviewed publications) to generate sufficient facts or data to base their findings on. Good record keeping should be practiced, especially where subjective decisions are made. When sufficient facts or data are generated to support the expert's opinion, a written report should be produced. The report should highlight relevant facts, which may include: the author of the report, the chain of custody of the evidence, techniques and/or methods applied, and results obtained. Supporting documents should be added to prohibit any surprises or discoveries made by the opposing counsel. This will ensure transparency and objectivity from the side of the expert.

The third part refers to the process will be acceptance of both the evidence (report) and expert testimony. The judge will ultimately be responsible (as gatekeeper) to admit or dismiss evidence or the expert from the trial. He/she will either use *Frye*, *Daubert*, Rule 702, a combination of them, or similar rules stipulated by the jurisdictions they serve under. The judge will decide on the relevance of the evidence, whether the qualification, skills, training or experience of the expert is sufficient to qualify the person as an expert witness or an *ad hoc* witness. The judge needs to clearly specify the criteria followed to admit or reject evidence as the judge's decision is in some instances subject to authority and standing of a higher court that may overrule their decisions (such as supreme or appeal courts).

The fourth part relates to the trial where the report and evidence can serve as *prima facie* evidence without the presence of the expert, or a request that the expert needs to testify on the evidence to support the court on the trier of fact. The witness will then testify to what is covered within the report. The expert may formalise an opinion based on sufficient facts and data obtained, as well as inferences made from the data. The expert should be cautious not to defend the evidence or the value thereof, but rather stay with the facts surrounding the opinion, within the boundaries of that discipline.

As in any adversarial system, the expert will be examined and cross-examined by both counsel, whose efforts will either be to lead the expert to overstate the value of the evidence or discredit the expert or the reliability of the technique or method used. The jury or judge will be the arbitrator of the court on deciding whether the evidence is of value and presented reliably by the expert witness.

The following chapters will focus on the development of and challenges to scientific evidence, and how the law and other external factors contributed to the development.

4.1 Introduction

It is difficult to imagine a world without cameras to capture and store images of objects; not being able to distinguish between people based on their DNA or fingerprints; a world without instruments to identify molecular structures, or microscopes to examine particles or objects. All of these discoveries, made by physicists, engineers, doctors, anatomists and others, happened over centuries. Hypotheses were set, they were tested through experimental work, and the scientific method was developed, not always in a structured manner, as we know today.

In this chapter, the focus will shift to scientific developments that contributed to forensic science and the law prior to the 20th century. A chapter detailing some of the key historical developments related to forensic science is necessary in order to provide a more contextualised understanding of the challenges facing forensic science in present times, as well as provide an overview of key developments whose impact and future scope can only be fully comprehended with reference to these. A historical overview also allows a researcher to understand the foundational development of scientific methods within forensic disciplines and will assist legal professionals when deciding whether a forensic discipline meets the standards of a scientific method.

The origin of developments in forensic science derives from the scientific principles of Francis Bacon,³¹⁸ better known as the father of empiricism, at a time when the natural world had to be examined to discover important truths about it. In forensic science, the natural world is presented in a form of evidence relating to crime scene investigations, relying on ways to solve crime through scientific and empirical observations. During the early times, repeated patterns emerged during observations and displayed the truth regarding how the natural world functioned. The early observations were not held to the same scientific scrutiny as they are today.

³¹⁸ Stanford Encyclopedia of Philosophy "*Francis Bacon*" First published 2003-12-29; substantive revision 2012-12-07. <https://plato.stanford.edu/entries/francis-bacon/> (Date of use: 8 April 2019).

These early discoveries should be seen for their contribution and value at that time. As time progressed, technology changed, forensic science became discipline-specific and certain gaps started appearing in its foundations. It will, however, be unfair if no credit is given to these early discoveries and their foundational contributions within each forensic discipline are not acknowledged. The brief historical overview below will highlight, in chronological order, some of the key events and developments which significantly influenced the development of forensic science in its current state.

4.2 History BC to the end of the 15th century

The scientific method in forensic-related discoveries evolved over time, with some of history's greatest and most influential minds adding to and refining the process. Whilst many point to Aristotle and the Greek philosophers as the primary driving force behind the development of the scientific method, this is often exaggerated. Although the Greeks were the first Western civilization to adopt observation and measurement as part of learning about the world, this was not sufficiently structured at the time to be viewed as the scientific method.³¹⁹ These ancient philosophers did not follow or believe in empiricism, and saw measurements as a form of arts and crafts. One of these philosophers, Plato, believed that knowledge is obtained through reasoning and not measurement.³²⁰

Although it is fair to regard Aristotle as the founder of empirical science, the development of a scientific process resembling the modern method was primarily developed by Muslim scholars³²¹ during the Golden age of Islam, and refined by the Enlightenment scientist-philosophers.³²²

³¹⁹ Lloyd GER *Magic, Reason and Experience: Studies in the Origin and Development of Greek Science* (Cambridge University Press 1979).

³²⁰ Internet Encyclopedia of Philosophy "*Plato (427—347 B.C.E.)*" A peer-reviewed Academic Resource. <https://www.iep.utm.edu/plato/> (Date of use: 8 April 2019).

³²¹ Prioreshi P "Al-Kindi, A Precursor of the Scientific Revolution" 2002 *J Int Soc History of Islamic Med* (2):17–19. Also: Lindberg DC *Theories of Vision from Al-Kindi to Kepler* (Chicago Univ of Chicago Pr 1976). Also: El-Bizri N "A Philosophical Perspective on Alhazen's Optics" 2005 *Arabic Sci and Phil* 15(2):189–218.

³²² Stanford Encyclopedia of Philosophy "*Enlightenment*" First published 2010-09-20; substantive revision 2017-09-29. <https://plato.stanford.edu/entries/enlightenment/> (Date of use: 7 January 2020).

The Eureka legend of Archimedes (287- 212BC)³²³ is considered an early account of the use of chemistry and physics. Archimedes determined that a crown, ordered by his friend, King Heiro II, was not completely made of gold, as was fraudulently claimed by the goldsmith. He was said to have determined the density of the crown by placing the crown into water and measuring the displacement of the water level, after which he took the weight of the crown and divided the volume of water displacement therein. The density value calculated in this process differed from the known density of an equal amount of pure gold. He informed the king that the goldsmith had deceived him and that cheaper, less expensive metals were added to the crown to cut costs on the part of the goldsmith. This method of density determination is still used in liquid dynamics and the same principles are used in forensic sciences today.³²⁴

During the 700's, Chinese researchers discovered and used fingerprints to establish identity of documents and clay sculpture, although they did not have any formal classification system and did not know the value of uniqueness and persistence of fingerprints at the time.³²⁵ During the early 1000's (circa), Quintilian, an attorney in the Roman courts, showed that bloody palm prints were meant to frame a blind man for his mother's murder. In 1248, a Chinese book, *Hsi Duan Yu* (The washing away of wrongs),³²⁶ contained a description of how to distinguish between drowning victims and strangulation victims. This was the first recorded application of medical knowledge to the solution of crime. In 1540, Ambroise Pare, a French pioneer in surgery, conducted a study on the effect of injuries made by arrows and gunshots on the internal organs. He also published the first book on forensic pathology.³²⁷

³²³ Encyclopædia Britannica "Archimedes' principle" 1998-07-20.

<https://www.britannica.com/science/Archimedes-principle> (Date of use: 30 January 2018).

³²⁴ History of Archimedes http://www.bbc.co.uk/history/historic_figures/archimedes.shtml (Date of use: 30 January 2018).

³²⁵ National Institute of Justice *Fingerprint Sourcebook* 2005.

³²⁶ James SH et al. *Forensic Science: An Introduction to Scientific and Investigative Techniques* (CRC Press 2005).

³²⁷ Smith S *The History and Development of Legal Medicine, Legal medicine* (RBH Gradwohl St. Louis: CV Mosby 1954) 8.

4.3 Key historical developments during the 17th and 18th century

The first treatise on systematic document examination was published in 1609 in France by François Demelle.³²⁸ He claimed that handwriting revealed a person's character just as well as physiognomy. A second paper on the same topic was published in 1665 by another Frenchman, Jacques Raveneau.³²⁹ There is also mention of other works in the interpretation of handwriting, including those of the Italian, Camille Baldo, in 1622.³³⁰ Also in 1665, Charles Ainsworth Mitchell from Great Britain conducted extensive work on questioned document identification. His focus was not limited to handwriting comparison, but he also studied the chemistry of inks, a different aspect entirely.³³¹

The innovation of the autopsy, one of the first applications of science to criminal investigations, became known as legal medicine. In 1685, Govard Bidloo, a Dutch anatomist, published the *Anatomy of the Human Body*, which included details of the skin and the papillary ridges of the thumb, but failed to address individualisation or permanence.³³²

Marcello Malpighi (1628-1694), an anatomy professor, referred to as the "Father of microscopical-anatomy, histology, physiology and embryology", used microscopic techniques to characterise fingerprints.³³³ The value of these techniques as a tool for individual identification was not mentioned at the time.

The first well-documented trial of poisoning was that of Mary Blandy. Blandy was hanged in 1752 for the murder of her father, Francis Blandy, a prosperous lawyer and the Town Clerk of Henley

³²⁸ Inman *Practice of Criminalistics* 2001.

³²⁹ Raveneau J " *Traité des inscriptions en faux et reconnoissances d'ecritures & signatures par comparaison & autrement*" Bibliothèque nationale de France, 1665. Translate to (" *Treaty of forgeries and recognitions of scriptures & signatures by comparison & otherwise*" National Library of France) <http://www.historyofinformation.com/detail.php?id=3290> (Date of use: 8 April 2018).

³³⁰ Grant D "Handwriting Analysis and the Police Officer" 1944 *Police J (London)* XVII (3):204.

³³¹ Inman *Practice of Criminalistics* 2001.

³³² Ashbaugh DR *Quantitative-Qualitative Friction Ridge Analysis: An Introduction to Basic and Advanced Ridgeology* (CRC Press Boca Raton FL 1999).

³³³ Ghosh SK and Kumar A "Marcello Malpighi (1628-1694): Pioneer of microscopic anatomy and exponent of the scientific revolution of the 17th Century" 2018 *European J of Anatomy* 22(5):433-439.

on Thames in Oxfordshire.³³⁴ The trial took place at Oxford Assizes in March 1752, before the Honorable Heneage Legge, Esq., and Sir Sydney Stafford Smythe, in the hall of the Divinity School. The trial was of particular interest because it was the first time that detailed medical evidence was presented in court on a charge of murder by poisoning. Although Dr. Anthony Addington had not been able to chemically analyse Francis Blandy's organs for traces of arsenic, as the technology to do so were non-existent at the time, he was able to convince the court on the basis of observed comparison that the powder that Mary had put into her father's food was indeed arsenic.

In 1784 in Lancaster, England, John Toms was convicted of murdering Edward Culshaw with a pistol. In the wound, a torn edge of a wad of newspaper was noted, the latter used to secure powder and balls in the muzzle of a pistol, matching a remaining piece of newspaper in his pocket. This was one of the first documented uses of physical matching.³³⁵

The discovery that fingerprints were unique to each individual and could provide identification of a particular individual, pushed the state of forensic crime investigation to the forefront in 1788 when Dr. Nathaniel Grew published an illustrated anatomy book in which he claimed that "the arrangement of skin ridges is never duplicated in two persons."³³⁶ Although friction ridge skin had been studied for a number of years, it was only in 1788 that the uniqueness of this part of the skin became recognised in Europe. This uniqueness was related to patterns and detail on all ten fingers from one individual to another. A number of forensic examiners later misinterpreted this to partial parts of a single latent print to be unique to an individual.³³⁷

³³⁴ Roughead W "The Trial of Mary Blandy" 2004-06-16. <http://www.gutenberg.org/files/12640/12640-h/12640-h.htm> (Date of use: 16 January 2018).

³³⁵ "Wednesday's Post British Newspaper Archive 1784-01-30 Chelmsford Chronicle. <http://www.britishnewspaperarchive.co.uk>. (Date of use: 29 December, 2018).

³³⁶ NIJ *Fingerprint Sourcebook* 2005.

³³⁷ NIJ *Fingerprint Sourcebook* 2005.

4.4 Key historical developments during the 19th century

The first use of science in a legal matter exposing forgery occurred in Germany in 1810, when a particular dye in ink from a document known as the “*Königin Handschrift*” was analysed. Unfortunately, the chemical used in the analysis destroyed the document and German courts disallowed the chemical test for the next six years.³³⁸ Mathiew Orfila (1787–1853), a Spaniard who became professor of medicinal/forensic chemistry at University of Paris, published “*Traite des Poisons Tires des Regnes Mineral, Vegetal et Animal, ou Toxicologie General I*” in 1813.³³⁹ He was later considered the “Father of modern toxicology”. He also made significant contributions to the development of tests for the presence of blood in a forensic context and is credited for the first to attempt the use of a microscope in the assessment of blood and semen stains.³⁴⁰ There was some controversy in the early 19th century about whether microscopical examination or chemical tests should have priority in examining bloodstains or semen stains, especially regarding which of these should be seen as giving more reliable results.³⁴¹

John Evangelist Purkinji, a professor of anatomy at the University of Breslau, Czechoslovakia, published the first paper on the nature of fingerprints in 1823. He suggested a classification system based on nine major pattern types, but did not recognise their individualising potential at the time.³⁴²

In 1835, Henry Goddard, a former Bow Street Runner employed by Scotland Yard was involved in the first documented case of law enforcement where the comparing of bullets was used to convict the suspect. Goddard observed a flaw on the fired bullet similar to a mark within the original bullet mold.³⁴³ One year later, in 1836, James Marsh developed the so-called Marsh test, the first

³³⁸ Robinson HM *Science vs. Crime* (New York: Bobbs-Merrill 1935).

³³⁹ Orfila M *Traite des Poisons Tires des Regnes Mineral, Vegetal et Animal, ou Toxicologie General I* (Crochard Parigi 1827). (Translated to *Treats of Poisons from the Mineral, Vegetal and Animal Reigns, or General Toxicology I*).

³⁴⁰ Gaensslen RE *Sourcebook in Forensic Serology, Immunology, and Biochemistry* (US Department of Justice 1983) 21. https://www.ncjrs.gov/pdffiles1/pr/92422_part1.pdf (Date of use: 14 August 2018).

³⁴¹ Gaensslen *Forensic Serology* 1983.

³⁴² NIJ *Fingerprint Sourcebook* 2005.

³⁴³ Hamby JE “The History of Firearm and Toolmark Identification” 1999 *AFTE J 30th Anniversary Issue* 31(3):266-284

reliable analysis that could show scientifically that arsenic was present in the body of a victim.³⁴⁴ Marsh was presented with a gold medal by the Society of Arts of London on April 22, 1836, for this “valuable contribution.” The London Medical Gazette published Marsh’s article, titled the “Account of a new method of separating small quantities of arsenic from substances with which it may be mixed” in the same year.³⁴⁵ The test referred to in the article was based on contact between arsenical material with liberated hydrogen by the action of zinc and acid. Metallic arsenic was observed as a deposited metallic mirror after ignition of the gas.

The case reported by Orfila, Barruel and Chevallier in 1835 is interesting in that the blood identification procedure developed by Orfila, and the "odour test" for human species identification developed by Barruel, were applied to case materials.³⁴⁶ Orfila was known for assessing techniques developed by other scientists. He published one of his assessments in 1845 on the hypochlorous acid test for human blood developed by Professor Persoz.³⁴⁷

Henri-Louis Bayard was one of the earliest practitioners of legal medicine, known today as forensic science.³⁴⁸ Bayard’s most notable scientific achievements were recorded in 1839 after Anthony van Leeuwenhoek first observed and identified sperm cells by using a microscope. It was Bayard who published the first paper considered the “gold standard” for evidentiary use, on detecting sperm under the microscope. He also contributed substantially on the understanding and observation of distinct fiber characteristics.³⁴⁹

In 1853, Professor Ludwig Teichmann from Kracow, Poland, developed the first microscopic crystal test for hemoglobin using hemin crystals, the technique known today as microcrystalline testing using Teichmann crystals or the hemin test.³⁵⁰ Louis Lewin (1850-1929), a German pharmacologist, studied and classified hallucinogenic plants, alcohols, and other psychoactive

³⁴⁴ James M “Account of a method of separating small quantities of arsenic from substances with which it may be mixed” 1836 *Edinburgh New Phil J* 21:229–236.

³⁴⁵ Hempel S “James Marsh and the poison panic” 2013 *The art of medicine* 381(9885):2247-2248.

³⁴⁶ Orfila MJB *Chemistry, Medicine, and Crime* (Science History Publications 2006).

³⁴⁷ Gaensslen *Forensic Serology* 1983.

³⁴⁸ Rosenfeld D and Faircloth C *Medicalized Masculinities* (Temple University Press 2006).

³⁴⁹ Inman *Practice of Criminalistics* 2001.

³⁵⁰ Bell S *Encyclopedia of Forensic Science* (Facts on File Inc 2008) 186.

compounds in 1854.³⁵¹ This was followed by the isolation of cocaine from the South American plant, *Erythroxylon coca* in 1855 by Friedrich Gaedcke.³⁵²

Sir William Herschel, a British officer working for the Indian Civil service, began in 1856 to use thumbprints on documents, both as a substitute for written signatures for illiterate persons and to verify document signatures.³⁵³ Also in 1856, German anthropologist Hermann Welcker of the University of Halle, led the way in the study of friction ridge skin permanence. Hermann Welcker began by printing his own right hand in 1856 and then again in 1897, thus gaining credit as the first person to start a permanence study.³⁵⁴

In 1862, Ernst Hoppe-Seyler published a paper on the behavior of hemoglobin in the spectrum of sunlight.³⁵⁵ Also in the same year, Isaac Van Deen described the guaiacum test for detection of blood.³⁵⁶ It was a catalytic test based on the peroxidase activity of hemoglobin and its derivatives. It was later replaced by the more sensitive benzidine test.³⁵⁷ During the same period, in 1863, the German scientist, Christian Schönbein, first discovered the ability of hemoglobin to oxidise hydrogen peroxide, making it foam. The chemical oxidation reaction caused a physical change to blood and could be performed on the crime scene and serve as a first presumptive test for blood.³⁵⁸ Both tests, however, depended on the oxidising property of heme. A limitation was the fact that both tests occasionally produced false positives with substances other than blood.³⁵⁹

³⁵¹ Macht DI "Louis Lewin: pharmacologist, toxicologist, medical historian" 1931 *Ann Med Hist* 3:179–194.

³⁵² Tewari A and Tiwari S *Synthesis of Medecine Agents from Plants* (Elsevier 2018).

³⁵³ NIJ "Fingerprint sourcebook" 2005

³⁵⁴ Wilder and Wentworth *Personal identification; methods for the identification of individuals, living or dead* (Boston RG Badger publishers 1918).

³⁵⁵ Perutz M "Hoppe-Seyler, Stokes and hemoglobin" 1995 *US National Library of Medicine National Institutes of Health Biol Chem Hoppe Seyler* 376(8):449-50.

³⁵⁶ Bell S *Oxford Dictionary of Forensic Science* (Oxford University Press 2012).

³⁵⁷ Taylor AS "Detection of blood in medico-legal cases"
https://archive.org/stream/b28271233/b28271233_djvu.txt (Date of use: 31 January 2018).

³⁵⁸ Inman *Practice of Criminalistics* 2001.

³⁵⁹ Gardner RM and Krouskup D *Practical Crime Scene Processing and Investigation* (CRC Press 2nd ed 2012).

During the Civil War in the United States in 1863, Confederate General Stonewall Jackson sustained three gunshot wounds at the Battle of Chancellorsville.³⁶⁰ One of the bullets, which remained in his right hand, was subsequently removed and examined. The firearm expert identified the object as a .67 caliber ball projectile from a smooth bore musket. As the Union Army only used a .58 caliber Minnie ball projectile in their firearms collection, it was concluded that Jackson had been shot by Confederate soldiers. Jackson died eight days later. In similar vein, in 1864, Union General John Sedgwick was shot and killed in battle by a single projectile fired by a Confederate sniper from an estimated distance of eight hundred yards.³⁶¹ When the bullet was removed, a determination of bullet type was made, based on the caliber and hexagonal shape of the bullet. This particular caliber and shape of bullet was consistent with the Whitworth rifles imported from England by the Confederate forces.³⁶²

In 1864, Odelbrecht advocated the use of photography for the identification of criminals in his book, "The Use of Photography in the Penal Process". He also suggested the use of photography in identifying corpses, recording crime scenes, documents, and discovery of articles and objects of dispute.³⁶³ Three years later, in 1867, a photograph of a crime scene invalidated the testimony of an eyewitness and the value of photography from thereon received widespread recognition.³⁶⁴ Also in 1876, testimony was given for the first time regarding the examination of a blood stain, particularly to the species of origin.³⁶⁵ In 1877, photomicrographs of laboratory tests of stains were admitted in court to ascertain whether blood was of human origin.³⁶⁶

³⁶⁰ Cullen JP *Battle of Chancellorsville*. In: *Battle Chronicles of the Civil War: 1863*, edited by McPherson JM Connecticut (Grey Castle Press 1989). First published in 1989 by McMillan.

³⁶¹ Winslow RE General John Sedgwick: *The Story of a Union Corps Commander* (Novato, CA: Presidio Press 1982).

³⁶² McCollum I "Confederate Whitworth Sniper: Hexagonal Bullets in 1860" 2017-10-12 Forgotten Weapons.com. <https://www.forgottenweapons.com/confederate-whitworth-sniper-sub-moa-hexagonal-bullets-in-1860/> (Date of use: 8 April 2018).

³⁶³ Stenger E *The history of photography- Its relation to civilization and practice* (Easton Pa: Mack Printing 1939).

³⁶⁴ Stenger *Photography* 1939.

³⁶⁵ Stowel CH *Some expert testimony: The microscope and its relation to Medicine and Science III* 4 Oct. 1883 [157].

³⁶⁶ Stenger *Photography* 1939 [108].

The first cited cases where firearm and bullet testimony were used in the United States date back to 1876 (Georgia),³⁶⁷ 1883 (Texas),³⁶⁸ and 1889 (South Carolina).³⁶⁹ In 1877, Thomas Taylor, a microscopist for the United States Department of Agriculture, presented a lecture concerning palm prints and prints from the tip of fingers, and their possible applications concerning crime solving. Taylor proposed the idea of using bloody prints found at crime scenes as a means to identify suspects. The lecture was published in the July 1877 issue of “*The American Journal of Microscopy and Popular Science*”.³⁷⁰

Rudolph Virchow, a German pathologist, was the first to use hair analysis in criminal investigation, and recognised its limitations in 1879. His analytical work included the analyses of the hair, skin and eye colour of school children.³⁷¹ Also in 1879, a Minnesota court allowed the opinion of an expert to testify on the presence of rifling marks on a fatal bullet. The expert excluded the possibility of the bullet having been fired from one weapon and confirmed that the rifling marks were consistent with the bullet being fired from a second weapon.³⁷²

Henry Faulds, a Scottish physician working in Tokyo, published a paper in 1880 in the journal *Nature*, suggesting that fingerprints at the scene of a crime could identify the offender.³⁷³ He utilised this technique to solve the first case involving fingerprints. He excluded a suspect to a Tokyo burglary as the perpetrator to the crime. In his book, titled “*Life on the Mississippi*”, Mark Twain writes of a murderer identified by fingerprint identification. The first legal recognition of this process had been realised nearly a decade earlier in 1882 during a case involving document forgery in New Mexico, constituting the first official use of the technique in the United States.

³⁶⁷ *Moughan v. State* 57 Ga 102, 1876.

³⁶⁸ *Meyers v. State* 14 Tex App. 35, 1883.

³⁶⁹ *State v. Davis* 33S.E.449, 55 SC 339, 1889.

³⁷⁰ Henry S “A Practical treatise on lightning protection” 1877 *The Am J of Microscopy and Popular Sci* 89. <https://babel.hathitrust.org/cgi/pt?id=hvd.32044081507261;view=1up;seq=295> (Date of use: 9 October 2018).

³⁷¹ Committee on Science, Technology, and Law, Federal Judicial Center, National Research Council, Policy and Global Affairs, Committee on the Development of the 3rd Edition of the Reference Manual on Scientific Evidence. Reference Manual on Scientific Evidence (US: National Academies Press 2011) 112.

³⁷² *State of Minnesota v. Edward Lawlor*, 28 Minn. 216, 1879.

³⁷³ Faulds H *The guide to fingerprint identification* (Hanley: Wood, Mitchel and Co Ltd Printers and Publishers 1905).

In 1888, Arthur Conan Doyle, the creator of fictional crime stories, better known as the Sherlock Holmes detective stories, published his first story, “*A Study in Scarlet*” in Beeton’s Christmas³⁷⁴ Annual, introducing the immortal Sherlock Holmes and Dr. Watson. He continued to write a further 59 Sherlock Holmes crime stories.³⁷⁵ Edmund Locard, to whom the concept of transfer exchange, referred to in chapter two of this study is attributed, gave direct credit to Arthur Conan Doyle, innovator of the fictional detective Sherlock Holmes, as the true founder of modern forensic science.³⁷⁶

Alexandre Lacassagne is generally recognised as the first scientist to try to match an individual bullet to a gun barrel. He did this by examining the bullet’s striations, counting and comparing the number of lands and grooves. He realised more systematic research should be done. He continued to research various brands of revolvers and recorded the types of striations transferred to projectiles. He discovered that the striations on the bullets could be used to identify an individual weapon, the brand or make of a revolver. This is better known today as class characteristics and sub-class characteristics. In 1889, Lacassagne published the article, “*La Deformation des Balles de Revolver*”, in the *Archive de Antropologie Criminelle et des Sciences Penales*, outlining his findings regarding bullet markings.³⁷⁷ Although he did not come up with a system to classify these markings, Lacassagne’s research and study is considered as the beginning of the science of ballistics. Lacassagne worked as a professor of forensic medicine at the University of Lyons, France. Many prominent forensic scientists at the time had the opportunity to study under his supervision, including Edmund Locard, creator of the “Locard Principle” and the founder of the

³⁷⁴ Doyle AD *A Study in Scarlet* (Ward Lock & Co 1st ed 1887).

³⁷⁵ Berg SO “Sherlock Holmes: Father of scientific crime detection” 1971 *J Crim Law Crim & Police Sci* 61(3):446.

³⁷⁶ Inman “Practice of Criminalistics” 2001.

³⁷⁷ Le Fort, Potain and Regnaud “*Bulletin général de thérapeutique médicale, chirurgicale*” (Paris Doin Administrateur Gerant 1889) 469.
https://books.google.com/books?id=vdW2DF5a18UC&pg=PA469&lpg=PA469&dq=La+Deformati+on+des+Balles+de+Revolver&source=bl&ots=9_NIU9LpJT&sig=ACfU3U305D9A1aLv7r_tX6ZQE_O_MRffVEw&hl=en&sa=X&ved=2ahUKEwi8jKKW1fTmAhXsIOAKHVdKANwQ6AEwDHoECAsQAQ#v=onepage&q=La%20Deformation%20des%20Balles%20de%20Revolver&f=false (Date of use: 8 January 2020).

world's first forensic laboratory in the 1900s.³⁷⁸ Lacassagne also was one of the first scientists to study and report on the significance of bloodstains left at a crime scene, and what these stains could indicate about the nature of the crime committed. In particular, he conducted research on the relation between the shape of blood spots and the position of the victim.³⁷⁹

The publication of Austrian criminologist Hans Gross's "*Handbuch für Untersuchungsrichter als System Der Kriminalistik*" (translated into English as *Criminal Investigation*) in 1893, further promoted the establishment of the science of forensics, especially in terms of a cross-transfer of evidence, such as dirt, fingerprints, carpet fibers, or hair, from the criminal to the victim.³⁸⁰

In 1891, the French medical/legal scientist, Rene Forgeot, published a thesis in which he proposed using powders and chemicals to develop latent prints at crime scenes in order to individualise the person who had touched an object.³⁸¹ This was one of the earliest references on latent print development on crime scenes. A variety of available ingredients to make dusting powders were suggested, including charcoal, lead powder, cigar ashes, soot, and talc.³⁸² The idea behind using powders was for the powder to adhere to the latent prints left behind on crime scenes to provide good visibility and provide separation between the print and the substrate it was deposited on. A combination of pigments and powders were thereafter developed to act as an adhesive to the latent print residue without "painting" the surface (substrate) it was deposited on.³⁸³

In 1892, (Sir) Francis Galton, after many years of intensive research of all ten human fingers and not just the thumbs, published a book titled "*Fingerprints*".³⁸⁴ He covered the nature of fingerprints

³⁷⁸ Lucas DM "Forensic Science in the Nineteenth and Twentieth Centuries" 2014 Bruinsma G, Weisburd D (eds) *Encyclopedia of Criminology and Criminal Justice* (Springer New York NY 2013).

³⁷⁹ Renneville M *La criminologie perdue d'Alexandre Lacassagne (1843-1924) Histoire de la criminology, Crimino Corpus*. <https://journals.openedition.org/criminocorpus/112> (Date of use: 10 June 2018).

³⁸⁰ Gross H *Handbuch für untersuchungsrichter als system der Kriminalistik* (Nabu Press 2012).

³⁸¹ Forgeot R "Atude Midico-Ligale des empreintes peu visibles ou invisibles et revelees par des procedes speciaux" 1891 *Archives d'Anthropologie Criminelle* 6 387-404. (Photostat, Trustees, British Museum). Translate as ("Medico-Legal study of invisible or invisible fingerprints and revealed by special procedures" *Archives of Criminal Anthropology*).

³⁸² Moenssens AA *Fingerprint Techniques* (Chilton Book Company: Philadelphia 1971). Also see Olsen RD *Scott's Fingerprint Mechanics* (Charles C Thomas: Springfield IL 1978).

³⁸³ Menzel ER *Fingerprint Detection with Lasers* (Marcel Dekker Inc: New York 2nd ed 1999).

³⁸⁴ Conklin BG et al. *Encyclopedia of Forensic Science: A Compendium of Detective Fact and Fiction* (Oryx Press 2002).

comprehensively and their use in solving crime. Galton established that friction ridge skin was unique and persistent. Galton was the first to define and name specific print minutiae, which became known as the Galton details.³⁸⁵ The next leading fingerprint researcher of the 19th century was Juan Vucetich. He was a statistician with the Central Police Department in La Plata, Argentina, and head of the bureau of Anthropometric Identification. Vucetich studied Galton's research and began to experiment with fingerprints in 1891. He started recording the fingerprints of criminals and developed his own classification system.³⁸⁶ Vucetich's classification system and individualisation of prisoners, through the use of fingerprints, were the first practical uses of the fingerprint science by law enforcement personnel.

In an assault case in 1892, a single hair sample recovered from the clothing of the victim could not be connected directly to any of two suspects, but indirectly to the dog of one of the two suspects. The finding led to the prosecution of the suspect.³⁸⁷

During a murder trial in Ohio in the United States in 1893, a blood stain on a bank note in possession of the suspect corresponded with similar stains found on a money wrapper located on the crime scene, playing a crucial role in the conviction of the perpetrator.³⁸⁸

Donogany described the production of hemochromogen crystals in 1893.³⁸⁹ In 1894, Alfred Dreyfus of France was convicted of treason based on handwriting evidence performed by Gobert, an expert of the Bank of France, whose testimony was pronounced "neutral", leading to a second enquiry made by Alphonse Bertillon, head of the "service de l'identité judiciaire" at the Prefecture of Police, whom Gobert had already entrusted with certain photographic enlargements of the bordereau. Bertillon's inference, based on a careful study of the relevant documents, was that:

³⁸⁵ Galton F *Finger Prints* (London MacMillen and Co 1892). <http://galton.org/books/finger-prints/galton-1892-fingerprints-1up.pdf> (Date of use: 8 January 2020).

³⁸⁶ Vucetich J "*Dactiloscopia comparada*" 1892 Made electronically available in 2007. <http://fama2.us.es/fde/ocr/2007/dactiloscopiaComparada.pdf> (Date of use: 8 January 2020).

³⁸⁷ Botanical Library "The Microscope and a Hai" 1892 *Am Monthly Microscopical J* XIII 8 Aug 191.

³⁸⁸ Botanical Library "Detection of Crime" 1892 *Am Monthly Microscopical J* XIV 8 Aug 240.

³⁸⁹ Miller LB "Hemochromogen Crystal Formation with Minute Amounts of Blood" 1969 *J Forensic Sci Soc* 9(1-2):84-86.

“If we set aside the idea of a document forged with the greatest care, it is manifestly evident that the same person has written all the papers given for examination, including the incriminating document.”³⁹⁰

The Dreyfus case was a series of connected military, civil and criminal proceedings, which began in 1894.³⁹¹ It is also considered the first exoneration of an innocent person based on misinterpretation of forensic evidence. A court-martial convicted Dreyfus of transmitting military secrets to Germany after which he was sentenced to life in prison on Devil’s Island. It was later discovered that the military fabricated evidence against Dreyfus prohibiting the re-opening of the case and a scandal to the French army and government. A fraudulent letter, purporting to be a letter from an Italian military attaché prompted the suicide of the colonel in military intelligence who had prepared it, leading to the resignations of the chief of the Army’s General Staff and the Minister of War. After five years on Devil’s Island, Dreyfus returned to a second court martial after France’s highest court, the *Cour de Cassation*, sitting *en banc* as a result of special legislation, vacated the judgment of the military court. Dreyfus was found guilty of treason for a second time in 1899 and was sentenced for a further five years in prison. However, the verdict was so poor that Dreyfus was pardoned by the President within two weeks after sentencing. Dreyfus was mistakenly identified through his handwriting in a report by the expert, Alphonse Bertillon.³⁹² In 1906, declaring that no credible evidence of treason ever existed, the court annulled the verdict of the Rennes court-martial. Dreyfus, the man twice convicted of treason, returned to the army and was awarded the cross of the Legion of Honor. It was only in 1995 that the army publicly declared his innocence.

The first cited fingerprint case arose in 1894, with the disappearance of a large amount of money which was transported from New York to New Jersey. A faint finger impression was discovered by David Carvallo, a document examiner, who questioned a broken wax seal of an envelope which had contained the key to the safe. The evidence pointed to one of seven express agents who had

³⁹⁰ Jacobs J “*Dreyfus Case (‘L’Affaire Dreyfus’)*” 1906 Jewish Encyclopedia.
<http://www.jewishencyclopedia.com/articles/5322-dreyfus-case-l-affaire-dreyfus> (Date of use: 10 September 2018).

³⁹¹ Kaye DH “Revisiting Dreyfus: A More Complete Account of a Trial by Mathematics” 2007 *Minnesota Law Rev* 91:825.

³⁹² Rhodes HTF *In the Tracks of Crime* (London: Turnstile Press 1952) 73.

access to the keys, namely Asa Gurney.³⁹³ In 1896, nearing the end of the 18th century, Sir Edward Richard Henry, developed a fingerprint classification system and with this recommendation, the Henry Classification System, a scientific filing system based upon alpha-numeric fingerprint identification and cataloging, was established. The individualisation of criminals by means of fingerprints through this system became standard practice in England and would eventually be adopted in most English-speaking countries in the early 1900's.³⁹⁴

One of the first recorded instances of expert witness testimony regarding the effects of firing a pistol at human hair and a paper target, occurred in a Kansas State (USA) Court in 1896. The defendant's legal team argued that the deceased committed suicide, but the counter argument was that it appeared that the hair around the bullet wound was not stained and no powder marks were visible on the flesh. If it was suicide, at least one of the two would have been present. The court permitted the expert witness (unknown), experienced in the use of firearms, to conduct various experiments using the evidence pistol and similar cartridges in an attempt to determine the effect on firing at hair and targets at close distances, between 6 inches to 10 feet. The witness, as a result of these experiments, was then allowed to provide testimony relating to the experiments.^{395,396} This type of analysis was further expanded by Corin, who published an article titled, "*La Determination de La Distance a'Laquelle un Coup de Feu a e'te' Tire*", in 1898.³⁹⁷ (The English translation of this contribution is "Determination of the distance at which a shot has been discharged from a firearm").

The early 1890's saw the first commercially available pistols, which brought a new dimension in forensic firearm investigations. Instead of finding just projectiles on crime scenes, crime scene investigators could now shift their focus to cartridge casings on the scene as well. Similar principles

³⁹³ Botanical Library "The Microscope in Detecting Crime" 1895 *Am Monthly Microscopical J XVI*: 5 152-153.

³⁹⁴ Tewari RK and Ravikumar KV "History and development of forensic science in India" 2000 *J Postgrad Med* 46: 303-308.

³⁹⁵ *State v. Asbell* 57, Kansas 398, 46 Pac. 770, 1896.

³⁹⁶ Rich BA and Wailes MB "American Law Reports" 1920 *Annotated Vol V III* 43.

³⁹⁷ Berg "Sherlock Holmes: Father of scientific crime" 1971.

of hard metals leaving striations on softer brass casings were followed in finding “individual characteristics”.

During a robbery and murder trial that took place near Pittsburgh, Pennsylvania in 1897, an important piece of trace evidence, a piece of glass found in the valise of the suspect, became the focus of attention. As this piece was not analysed before the trial, the prosecutor decided to bring a microscope into the court for the jurors to examine the piece of evidence. Fortunately for the prosecutor, one of the jurors was a glazier who was familiar with the inspection of glass. After the examination of the glass, he interpreted his findings to the other jurors, which assisted in the conviction of the accused.³⁹⁸

By the end of the 18th century, experts were not only examining the physical evidence, but were also publishing papers relating to their cases, theories, procedures and techniques. Due to “fierce competition of his day”, Daniel Ames intentionally omitted valuable information from his published work.³⁹⁹ Although Ames only withheld information that could have assisted his competitors on technical issues, others were not reluctant at all to share their technical expertise. Not only did they espouse their particular approaches, but also expressed disagreement with the views of other experts, which led to many protracted and heated debates in published works. One of the topics at the time of controversy was the attempt to determine the species of dried blood stains by measuring the diameter of rehabilitated erythrocytes.⁴⁰⁰ This debate continued until the introduction of Paul Uhlenhuth’s development of an anti-human sera for blood species determination.⁴⁰¹ Document examiners were also disagreeing on the significance of microscopic fluctuations in lines of writing allegedly caused by secondary rhythm said to be unique to an individual writer.⁴⁰²

³⁹⁸ Botanical Library “Murder” 1897 *Am Monthly Microscopical J XVIII* 31.

³⁹⁹ Osborn AS *Questioned documents* (Albany Boyd Printing Co 1929).

⁴⁰⁰ Stowell CH “Some Expert testimony” 1883 *The Microscope and its relation to Medicine and Science III: 4:157-58*.

⁴⁰¹ Botanical Library “The differentiation of Human and Animal Blood in the aid of specific serum” 1901 *Am Monthly Microscopical J XXII: 7:202*.

⁴⁰² Ames DT “Rhythm in Handwriting” 1881 *Am J of Microscopy and Popular Sci VI: 214*.

By the end of the 19th century, a number of scientific methods, foundational principles and terminology were established. Table 4.1 provides a summary of discoveries made before the 20st century.

Table 4.1 Scientific and observational discoveries made before the 20th Century

Year	Discovery	Credited to
287-212BC	Density of metals using liquid dynamics	Archimedes
1609	A systematic document examination process	François Danielle
1622	Interpretation of handwriting	Jacques Ravereau
1665	Chemistry of inks	Answorth Mitchell
1685	Details of skin and papillary ridges of thumb	Govard Bidlo
1628-1694	Fingerprint identification under microscope	Marchello Malpighi
1788	Uniqueness of fingerprints to an individual	Nathaniel Grew
1813	Blood and Semen Identification under microscope	Mathew Orfila
1823	Fingerprint Classification	Purkinji
1835	Comparing projectiles from firearms	Henry Goddard
1836	Marsh test- colour test for arsenic	James Marsh
1839	Fiber identification under microscope	Henri Bayard
1853	Microcrystal test for hemoglobin	Ludwig Teichman
1854	Classification of hallucinogenic plants	Louis Lewin
1855	Isolation of cocaine	Frederik Gaedcke

1863	First use of presumptive test on crime scene	Schönbein
1864	First use of photography recording criminals	Odelbrecht
1877	Identify bloody print on crime scene	Rudolph Virchow
1879	First hair analyses in criminal investigation	Thomas Taylor
1880	Connection between latent prints from crime scene to suspect	Henry Faulds
1889	Matching individual bullet striations to gun barrel Also study blood stains on crime scenes	Alexandre Lacassagne
1892	Fingerprints are unique and persistent	Francis Galton
1896	Scientific filing system for fingerprints	Edward Henry
1899	First exoneration of Dreyfus	

It is clear from the brief historical overview above that forensic science has not developed as a profession by itself, but as a science practised by a range of professionals, such as medical examiners, professors, anthropologists, scientists, and physicians. These specialists applied the laws of science to evidence. They were individuals with stature in their communities and their opinions were regarded highly in courtrooms at the time. Through their research, a solid foundation was laid for the next generation of scientists in the 20th century.

4.5 The growth of forensic science growth during the 20th and 21st century

No field illustrates the evolution of science better than forensic science. Despite its advances, the science has remained fundamentally the same. As more courts began to appreciate the value of

forensic evidence, the profession began to diversify into more specific disciplines, leading to the establishment of the first forensic science laboratory in Lyon, 1910.⁴⁰³

The start of the 20th century saw the gradual diminishing of scientists, anthropologists, microscopists, medical examiners and others, all previously conducting research and providing expert evidence on multiple disciplines, as the individual fields became more sophisticated and specialised. A clear separation between forensic chemistry, forensic biology, toxicology, firearms and fingerprint examination developed and each discipline formed their own entities. As the 20th century progressed, those entities developed into well-structured organisations with their own unique communities supporting their existence. The development of these organisations within the forensic community will be discussed in more detail in chapters five, six, seven and eight in this thesis.

The description of the historical development of forensic disciplines in this study follow the current structure of the Organisation of Scientific Area Committees (OSAC) for Forensic Science. It served as a guideline on categorising forensic disciplines covered. These disciplines are the following:

- (1) Chemistry/Instrumental analysis (Toxicology, Seized drugs, Materials/Trace, Gunshot residue, Geological materials, and Fire debris and Explosives);
- (2) Biology/DNA (Biological methods, Wild life forensics, and Biological data and Interpretation);
- (3) Physics/Pattern Interpretation (Friction ridge, Firearms and tool marks, Foot ware and tire, Bloodstain Pattern Analysis, and Forensic Document Examination).
- (4) Crime Scene/Death Investigation
- (5) Digital/Multimedia

⁴⁰³ Lucas DM "Forensic Science in the Nineteenth and Twentieth Centuries" In: Bruinsma G and Weisburd D *Encyclopedia of Criminology and Criminal Justice* (Springer New York NY 2014).

For the scope and purpose of this study, the focus will be on one forensic discipline from each major category (Crime Scene/Death investigation and Digital/Multimedia will not be covered) that is current and which combination encapsulates more than 90 per cent of forensic evidence in criminal proceedings.. Therefore, the focus will be on the following disciplines:

- (1) Chemistry/Instrumental analysis (Seized drugs);
- (2) Biology/DNA (Biological methods, and Biological data and Interpretation), and
- (3) Physics/Pattern Interpretation (Friction ridge, Firearms and tool marks).

Chapters five (controlled substances), six (forensic biology), seven (fingerprint examination) and eight (firearm and toolmark examination) present an evolution and continuation of scientific development within these forensic disciplines, as well as their contribution to the law, followed by an analysis of the challenges the law raised in response to the science in a number of leading cases. It will also demonstrate the growth of the forensic community into a recognised profession. Forensic science is no longer a “voodoo” science; nor a “pseudoscience”, but an integrated science within the science community, albeit with some shortcomings that will no doubt be resolved with continuous research and development.

CHAPTER 5 Controlled substances and seized drugs

5.1 Introduction

In the early 20th century, forensic chemistry emerged from the field of chemistry to deal with the application of chemical knowledge, principles, and procedures to civil and criminal law matters. Answers were generated in this field to address questions involving chemical compounds, products, or processes. Scientific developments gradually began to solve cases that could only be explained or resolved when analytical methods of investigation and instrumentation with chemistry as the main core were applied. Forensic disciplines became more distinct and technical to adapt to the challenges of scientific validity in various judicial proceedings. Similar to other fields, sub-branches also evolved in the discipline of forensic chemistry, such as toxicology, controlled substances, and explosives. A further influence on the development of the field was the number of discoveries and interventions in chemistry, and later forensic chemistry which entailed the qualitative analysis of chemical substances by separation using techniques of precipitation, extraction, or distillation.⁴⁰⁴ Forensic drug chemistry became the largest discipline in forensic crime laboratories, receiving thousands of samples per year to be analysed globally.

The development of the legislative framework, and how it was introduced and applied in science, is outlined in this chapter. This is followed by scientific developments introduced to the law, legislative and scientific challenges in criminal proceedings, and the need for standardisation both in national jurisdictions, and international investigations. Lastly, external and internal efforts to steer

⁴⁰⁴ Skoog DA and Leary JJ *The principles of instrumental Analysis* (Saunders College Publishers 4th ed Fort Worth Chapter 1: 1992).

the discipline towards a reliable and trustworthy supporting entity for the criminal justice system will be presented.

5.2 Introduction to regulation

The nineteenth century saw a continuation of national and international drug trade, but trading of these substances were now regulated under the supervision of governing authorities. A regulatory framework in this context always had and still has a two-tier objective; (1) to protect people from the exposure of harmful substances of abuse in an uncontrolled market, and (2) to give direction to forensic drug chemists on which substances are regulated within specific jurisdictions. The formulation of the legislation and exact wording used in legislation has always played a significant role in drug analysis and reporting of controlled substances. (See paragraph 5.2.3 on Isomer challenges).

5.2.1 Early legislation arising as a result of drug addiction

Prior to the 20th century, the regulatory focus was mostly on spirits (distillate alcohol) and tobacco. Regulation of opiates, coca plants, and cannabis (marijuana) started later in history. The Sumerians used opium around 5000 B.C.⁴⁰⁵, and the Lake Dwellers on Switzerland consumed poppy seeds around 2500 B.C.⁴⁰⁶ In 1800, Napoleon's army, returning from Egypt, introduced cannabis (hashish, marijuana) into France. The period 1839 to 1842 was known for the first Opium War. The British forced upon China the trade in opium; a trade the Chinese had declared illegal.⁴⁰⁷ Naturally occurring plants, such as Cocaine from *Erythroxylum novogranatense*, Opium from *Papaver Somniferum*, and Cannabis from *Cannabis Sativa Linne*, gained more and more interest internationally as physicians were looking for medical cures for their patients. In 1841, Dr Jacques Joseph Moreau used hashish in treatment of mental patients at the Bicetre.⁴⁰⁸ In 1844, cocaine was for the first time isolated in its pure form for medical use, because of its pharmaceutical

⁴⁰⁵ Lindesmith RA *Addiction and Opiates* (Routledge 2008).

⁴⁰⁶ Montagu A "The long search for euphoria" 1966 *Reflections 1*: 62-69 (May-June).

⁴⁰⁷ Montagu *Search of euphoria* 1966 [67].

⁴⁰⁸ Russo E "Cognoscenti of Cannabis I: Jacques-Joseph Moreau (1804-1884)" 2001 *Journal of Cannabis Therapeutics* Vol 1(1). <https://www.cannabis-med.org/data/pdf/2001-01-6.pdf> (Date of use: 12 February 2018).

properties as a stimulant and local anesthetic.⁴⁰⁹ A German army physician, Dr Theodor Aschenbrandt, secured a supply of pure cocaine from the pharmaceutical firm of Merck in 1883 and issued it to Bavarian soldiers to endure fatigue.⁴¹⁰

The popularity of these new found medicines also made it into the United States of America and ended up in the hands of unqualified distributors leading to an increase in recreational users. Regulations were needed to limit or control the distribution of medicines that were abused, and led to the establishment of the American Pharmaceutical Association in 1852.⁴¹¹ The Association established the first regulations of medicines to druggists and apothecaries.

At first, the regulations were limited to substances extracted from naturally occurring plants, but the discoveries of Friedrich August Kekulé in the late 1850s on carbon structuring and organic synthesis, combining molecules, led to synthetically producing substances that would later demand the regulation of both naturally occurring substances and synthetic compounds.⁴¹² Kekulé's discovery of benzene, an aromatic ring, opened up an extremely important, new field of chemistry called aromatic chemistry, and a new understanding of chemical bonding. In 1864, Adolf von Baeyer, a twenty-nine-year-old assistant of Friedrich August Kekulé in Ghent, synthesised barbituric acid, the first barbiturate which marked the start of designer medicines and drugs.

⁴⁰⁹ Osol A and Hoover JE *Remington's Pharmaceutical Sciences* (Easton Pa: Mack Publishing Co. 4th ed 1970).

⁴¹⁰ Aschenbrandt T *Die physiologische wirkung und die bedeutung des Cocains* (Deutsche medizinische Wochenschrift December 12, 1883); cited by Jones E *The life and work of Sigmund Freud* Volume I (1856-1900) (New York: Basic Books 1953).

⁴¹¹ Musto DF *The American Disease: Origins of Narcotic Drugs* (Oxford University Press 1973). The Association's 1856 Constitution lists one of its goals as: "To as much as possible restrict the dispensing and sale of medicines to regularly educated druggists and apothecaries.

⁴¹² Kekulé A "Über die s.g. gepaarten Verbindungen und die Theorie der mehratomigen Radicale" 1857 *Annalen der Chemie und Pharmacie* 104 (2): 129–150. Kekulé was a renowned German organic chemist who was the principal founder of the theory of chemical structure in organic chemistry. The first volume of his four volume book set detailing his discoveries "Lehrbuch der organischen Chemie" (Textbook of Organic Chemistry) was published in 1859. Today, these books serve as reference to many textbooks used to teach a foundation in Organic Chemistry.

In 1874, Diacetylmorphine (heroin) was semi-synthesised from opium for the first time by Alder Wright, an English chemist.⁴¹³ What was seen as a safe preparation free from addiction-forming properties at the time, turned out to be a highly addicting substance, both physically and psychologically.⁴¹⁴ The envisaged purpose for the substance to be used for medical reasons, became dominated by the need by countries to distribute opiates for economic gains. In 1906, an alarming 25 million people used opiates, almost 1.5 per cent of the international population. The number was spiraling out of control and a call for national and international control and regulation was made.⁴¹⁵

Four main reasons for the high addiction rates in the United States at the time were: (1) free dispensing of morphine to civil war veterans, (2) some Chinese immigrants introduced opium smoking to the United States, (3) heroin was introduced to the medical world as a cure for morphine addiction, and (4) opium and cocaine were common ingredients in patented medicines and sodas. The high addiction rates were alarming for many governing authorities and regulations had to be introduced to clamp down on the problem. Table 5.1 shows a brief historical development of legislation to counter drug trade and substance abuse since the beginning of the 20th century.

Table 5.1 Historical development of legislation on drugs of abuse and medicines

Regulation/Act	Year	Description
International Regulations		
International Opium Convention ⁴¹⁶	1912	The first international drug control treaty.
Updated International Opium Convention ⁴¹⁷	1925	Extension of first convention to include Cannabis control.
Updated International Opium Convention (Interpol)	1961 1971	Added more controlled substances and precursors under its ambit.

⁴¹³ Wright CRA "On the action of organic acids and their anhydrides on the natural alkaloids" (12 August 2003). Archived from the original on 6 June 2004. Note: this is an annotated excerpt of Wright, CRA "On the action of organic acids and their anhydrides on the natural alkaloids" 1874 *J Chem Soc* 27: 1031–1043.

⁴¹⁴ Montagu *Search of euphoria* 1966 [68].

⁴¹⁵ United Nations Office on Drugs and Crime (UNODC) "2008 *World Drug Report*" [176].

⁴¹⁶ International Opium Convention, League of Nations, 1912 *Treaty Series, vol. 8, 187. The Hague, 23 January 1912.*

⁴¹⁷ European Monitoring Centre for Drugs and Drug Addiction (EMCDDA) Monographs *A Cannabis reader: Global issues and local experiences* 2008.

Regulation/Act	Year	Description
	1988	
Single Convention on Narcotic Drugs ⁴¹⁸	1961	Prohibits production and supply of specific (nominally narcotic) drugs and of drugs with similar effects except under license for specific purposes, such as medical treatment and research.
Psychotropic Convention ⁴¹⁹	1971	Designed to control psychoactive drugs such as amphetamine-type stimulants, barbiturates, benzodiazepines, and psychedelics.
UN Drug Trafficking Convention ⁴²⁰	1988	Addresses more effectively the various aspects of illicit traffic in narcotic drugs and psychotropic substances having an international dimension.
Federal Regulations United States of America		
Pure Food and Drug Act ⁴²¹	1906	Prohibited the interstate shipment of misbranded or adulterated food and drugs.
Harrison Narcotics Tax Act ⁴²²	1914	Regulated and taxed the production, importation, and distribution of opiates and coca products
Jones -Miller Narcotic Drug Import and Export Act ⁴²³	1922	Eliminated use of narcotics, except for legitimate medicinal use.
Anti-Heroin Act ⁴²⁴	1924	Prohibited the importation and possession of opium for the chemical synthesis of an addictive narcotic, known as diacetylmorphine or heroin.
Marihuana Tax Act ⁴²⁵	1937	Introduced a tax on the sale of cannabis.
Food, Drug, and Cosmetic Act ⁴²⁶	1938	Provided the FDA with control over drug safety.

⁴¹⁸ United Nations Office on Drugs and Crime “*Single Convention on Narcotic Drugs*” 1961. See https://www.unodc.org/pdf/convention_1961_en.pdf (Date of use: 4 April 2019).

⁴¹⁹ United Nations Office on Drugs and Crime, *Convention on Psychotropic Substances*, 1971. See https://www.unodc.org/pdf/convention_1971_en.pdf (Date of use: 4 April 2019).

⁴²⁰ United Nations Office on Drugs and Crime, *United Nations Convention against Illicit Traffic in Narcotic Drugs and Psychotropic Substances*, 1988. See https://www.unodc.org/pdf/convention_1988_en.pdf (Date of use: 4 April 2019).

⁴²¹ Pure Food and Drug Act, Ch. 3915, 34 Stat. 768 (1906).

⁴²² Harrison Narcotics Tax Act, (Ch. 1, 38 Stat. 785), 1914. Proposed by Representative Francis Burton Harrison of New York and was approved on December 17, 1914.

⁴²³ 67th US Congress. Sess. II. Cris. 201, 202. 1922. The Narcotic Drugs Import and Export Act was a 1922 act of the 67th United States Congress. Sponsored by Sen. Wesley L. Jones of Washington and Rep. John F. Miller of Washington. It is also often referred to as the Jones-Miller Act.

⁴²⁴ 67th US Congress. Sess. I. Cris. 351-353. 1924. An Act prohibiting the importation of crude opium for the purpose of manufacturing heroin.

⁴²⁵ 75th US Congress. Marihuana Tax Act of 1937, Public Law 75–238, 50 Stat. 551. The H.R. 6385 act was drafted by Harry Anslinger and introduced by Rep. Robert L. Doughton of North Carolina, on April 14, 1937.

⁴²⁶ 75th US Congress. (Federal Food, Drug, and Cosmetic Act), Public Law 75-717, 52 STAT 1040, 1938. Prohibited the movement in interstate commerce of adulterated and misbranded food, drugs, devices, and cosmetics.

Regulation/Act	Year	Description
Opium Poppy Control Act ⁴²⁷	1942	Regulated the domestic control of the production and distribution of the opium poppy.
Durham-Humphrey Amendment ⁴²⁸	1951	Any drug that is habit-forming or potentially harmful, to be dispensed under the supervision of a health practitioner as a prescription drug
Drug Abuse Control Amendments ⁴²⁹	1965	Established special controls for depressant and stimulant drugs and counterfeit drugs.
Comprehensive Drug Abuse and Control Act ⁴³⁰	1970	Replaced and updated all previous laws concerning narcotics and other dangerous drugs.
Methadone Control Act ⁴³¹	1973	Established licensing regulations for those wishing to dispense methadone for opiate addiction.
Heroin Trafficking Act ⁴³²	1973	Increased penalties for distribution of opiates.
Analogue (Designer Drug) Act ⁴³³	1986	Enacted to deal with “designer” drugs, allowing immediate classification of a substance as a controlled substance.
Comprehensive Methamphetamine Control Act ⁴³⁴	1996	Mandated registration of persons trading in list I chemicals from the DEA list of chemicals.
Ecstasy Anti-Proliferation Act ⁴³⁵	2000	Scheduled club drugs with the controlled substances act by DEA, increased penalties for sale and use of club drugs.
Illicit Drug Anti-Proliferation Act ⁴³⁶	2003	A new law in the fight against ecstasy and predatory drugs, including amphetamines.
Positional Isomer clause to Controlled Substances Act ⁴³⁷	2007	Clarifies the interpretation of positional isomers.
Synthetic Drug Abuse Prevention Act of 2012 ⁴³⁸	2012	Regulates synthetic cannabimimetics and other designer drugs

⁴²⁷ The Opium Poppy Control Act of 1942, ch. 720, 56 Stat. 1045 (21 U.S.C. 188 et seq.), 1942. “To discharge more effectively the obligations of the United States under certain treaties relating to the manufacture and distribution of narcotic drugs, by providing for domestic control of the production and distribution of the opium poppy and its products, and for other purposes.”

⁴²⁸ 82nd US Congress, ch. 9 § 301 et seq., Durham-Humphrey Amendment, 1951. To amend sections 303 (c) and 503 (b) of the Federal Food, Drug, and Cosmetic Act, as amended in 1951.

⁴²⁹ Drug Abuse Control Amendments of 1965. Public Law 89-74, July 15, 1965, 79 Stat. 226.

⁴³⁰ 91st US Congress, ch. 13 § 801 et seq. ch. 13 § 951 et seq., Comprehensive Drug Abuse Prevention and Control Act of 1970.

⁴³¹ Narcotic Addict Treatment Act of 1974, 802 note. SEC. 2. Section 102 of the Controlled Substances Act (21 U.S.C. 802).

⁴³² 93rd US Congress, Heroin Trafficking Act, H.R. 7912 (93rd).

⁴³³ 99th US Congress, Analogue (Designer Drug) Act, 100 Stat. 3207, 21 U.S.C. § 813.

⁴³⁴ 104th US Congress, Comprehensive Methamphetamine Control Act, Public Law 104-237, 1996 110 Stat. 3099. Comprehensive Methamphetamine Control Act of 1996 is a bill (S. 1965) enacted into law (PL 104-237) by the 104th Congress of the United States.

⁴³⁵ 106th US Congress, Ecstasy Anti-Proliferation Act, §2612, H.R. 4365, 2000.

⁴³⁶ 108th US Congress, Illicit Drug Anti-Proliferation Act, Section 608 of §151, 2003.

⁴³⁷ Positional Isomer clause to Controlled Substances Act 21 CFR 1300.01(b) (21).

⁴³⁸ 112th Congress (2011-2012): Synthetic Drug Abuse Prevention Act of 2012, S.3190.

Regulation/Act	Year	Description
State Regulations of interest in the United States		
Colorado and Washington State ⁴³⁹	2012	First two states to legalise the recreational use of Cannabis Amendment 64 – Colorado Initiative 502 –Washington State
Ohio and Texas ⁴⁴⁰	2014	Pharmacophore Acts
Regulations in the United Kingdom		
Realm Act Regulation 40B ⁴⁴¹	1914	It made non-medical possession an offence and required a doctor's prescription for cocaine. Set on a path similar to that of America's Harrison Act of 1914.
Dangerous Drugs Act ⁴⁴²	1920	Issued controls over raw opium, morphine, cocaine, ecgonine, and heroin. The export, import, sale, distribution or possession of barbiturates, had to be licensed or authorised by the Home Secretary. Permitted doctors to prescribe dangerous drugs for medical treatment only.
Amendment the Dangerous Drug Act	1964 1967	Introduced criminal penalties for possession by individuals of small amounts of drugs, as well as possession with intent to traffic or deal in drugs
Misuse of Drugs Act ⁴⁴³	1971	Similar to Comprehensive Drug Abuse and Control Act 1970 of USA.
Drug Trafficking Offences Act ⁴⁴⁴	1986	Regulates the laundering the proceeds of drug trafficking.
Drug Act ⁴⁴⁵	2005	Prevents the misuse of controlled drugs
Psychoactive Substances Act ⁴⁴⁶	2016	Restricts the production, sale, and supply of a new class of psychoactive substances often referred to as "legal highs".
Regulations in South Africa		

⁴³⁹ Article XVIII, Section 16: Personal Use of Regulation of Marijuana, Colorado Constitution. November 6, 2012. Also Title 314 WAC, Washington Initiative Measure No. 502, November 2012.

⁴⁴⁰ Pharmacophore Acts Chapter 4729-11 Controlled Substances Schedules, April 2014.

⁴⁴¹ Parliament of the United Kingdom, Realm Act Regulation 40B, 4 & 5 Geo. 5 c. 29, 8 August 1914, United Kingdom of Great Britain and Ireland.

⁴⁴² Home Office, Dangerous Drugs Act 1920, Br Med J 1923; 1:69, 1920.

⁴⁴³ UK Public General Acts, Misuse of Drug Act, 1971 c. 38.

⁴⁴⁴ UK Public General Acts, Drug Trafficking Offences Act, 1986 c. 32.

⁴⁴⁵ UK Public General Acts, Drug Act, 2005 c. 17.

⁴⁴⁶ UK Public General Acts, Psychoactive Substances Act, 2016 c. 2.

Regulation/Act	Year	Description
Medical, Dental, and Pharmacy Act ⁴⁴⁷	1928	Prohibited the production, sale, and use of any "habit forming drugs".
Weeds Act ⁴⁴⁸	1937	Occupier or owner of a property had to prevent land being used to produce cannabis, or any other plant declared a 'weed'.
Abuse of Dependence-Producing Substances and Rehabilitation Centers Act ⁴⁴⁹	1971	Provides for the prohibition of the dealing in, and the use or possession of dependence-producing drugs.
Drugs and Drug Trafficking Act 140 ⁴⁵⁰	1992	Provides for the prohibition of the use or possession of, or the dealing in drugs, and of certain acts relating to the manufacture or supply of certain substances or the acquisition or conversion of the proceeds or certain crimes.

Table 5.1 shows that as time progressed, the relevant legislative provisions became more descriptive and comprehensive over the years, not only because of the increased number of substances that were illegally synthesised and listed due to their addictive properties, but also due to linguistic challenges during subsequent court trials.

The Pure Food and Drug Act of 1906 required distributors of food and drugs to label products when alcohol, morphine, cocaine, heroin, or any derivatives or preparations of these substances were present therein. It would allow consumers to decide whether they want to use the product after knowing the presence of such substances. The legislation did not prohibit use of the addictive substances and was consistent with a legitimate domestic traffic and sale of opium, morphine, heroin, and cocaine.

The Harrison Act of 1914 was by far the most significant statute of the early federal drug control laws in the United States. It set the tone for domestic drug control, and a year later the United Kingdom followed with the enactment of the Realm Act Regulation 40B, based on the Harrison Act. Both the Food and Drug act and the Harrison Act were in force until the 1970s. The Harrison

⁴⁴⁷ South African Government, Medical, Dental, and Pharmacy Act 13, Articles 61-70, 1928.

⁴⁴⁸ Senate Debates of the Union of South Africa, 10th May 1937, c. 1062.

⁴⁴⁹ South African Government, Abuse of Dependence-Producing Substances and Rehabilitation Centers Act 41 of 1971, 17th May, 1971.

⁴⁵⁰ South African Government Gazette, No. 140 of 1992: Drugs and Drug Trafficking Act, No. 14143, 15 July 1992.

Act allowed for federal surveillance of addiction-producing products from the point of entry or manufacturing to the end consumer. It also allowed for criminal penalties for those not in compliance. The Act had two main flaws: (1) Congress placed revenue powers in the hands of the Internal Revenue Service (IRS), rather than in the hands of law enforcement,⁴⁵¹ and (2) physicians were exempted from the dispensing and distribution of controlled drugs.⁴⁵²

With the new regulation on drugs, physicians became the sole source to support addicts' dependence on drugs. This was initially not a problem for the forensic chemist, but rather for law enforcement tasked with monitoring the "unscrupulous doctor" versus the "script doctor". A few Supreme Court decisions⁴⁵³ had the effect of limiting the powers of physicians to freely distribute controlled substances to addicts. Addicts at the time found new sources to support their addiction, namely the illicit market. In 1953, Rufus King⁴⁵⁴ aptly depicts the change as follows: "The addict-patient vanished; the addict-criminal emerged in his place."

The Dangerous Drug Act of 1920⁴⁵⁵ had a different approach to the medical profession in the United Kingdom. It permitted doctors to prescribe dangerous drugs for medical treatment, which included treatment for addiction as a medical condition. Morphine and heroin addiction numbers stayed low until the 1960s in the United Kingdom.⁴⁵⁶ The major difference between the United States system and the British system was that the one criminalised the problem of addiction by treating addicts as criminals, whereas the other medicalised the problem of addiction by treating addicts as patients.⁴⁵⁷

⁴⁵¹ Harrison Act of 1914 Ch. 1, 38 Stat. 785 (1914).

⁴⁵² Harrison Act of 1914 Ch. 1, § 2(a), 38 Stat. 785 at 786 (1914).

⁴⁵³ *Webb v. United States*, 249 U.S. 96 (1919); *Jin Fuey Moy v. United States*, 254 U.S. 189 (1920); *United States v. Behrman*, 258 U.S. 280 (1922). At one time, for instance, he had given an addict prescription for 150 grains of heroin, 360 grains of morphine and 210 grains of cocaine.

⁴⁵⁴ King R "The Narcotics Bureau and the Harrison Act: Jailing the Healers and the Sick" 1953 *Yale Law Rev* 62:736-749.

⁴⁵⁵ Dangerous Drugs Act, 1920, 10 & 11 Geo. 5, ch. 46. Dangerous Drugs and Poisons (amendment) Act, 1923, 13 & 14 Geo. 5, c. 5.

⁴⁵⁶ This evidence and statistical data is reported in Spear HB "The Growth of Heroin Addiction in the United Kingdom" 1969 *Brit J Addiction* 64:245-55. From 1921-1953 inclusive, official figures for criminal proceedings relate to prosecutions and from 1954 to the present, official figures relate to convictions. *Id.* at 246.

⁴⁵⁷ Bennett T *The British experience with heroin regulation* (Law and Contemporary Problems Senior Research Associate Institute of Criminology Cambridge England 1988).

South Africa faced a different type of substance addiction than those in the United States and the United Kingdom. The Medical, Dental, and Pharmacy Act of 1928 prohibited the production, sale, and use of any “habit forming drugs”, which limited the addiction of morphine and heroin, but could not control the widespread misuse or abuse of cannabis. The Senate of the Union of South Africa enacted the Weed Act on May 10, 1937, which prevented land owners and occupants of land to produce Cannabis, or any other plant declared a “weed”.⁴⁵⁸ The regulation placed pressure on botanists as chemical identification tests for cannabis or forensic drug chemists did not exist at the time. Botanists were expected to visually identify the cannabis plant and testify on macroscopic properties.

One of the earliest known challenges for chemists was from the Opium Poppy Control Act of 1942 in the United States. Section 2(c) of the Act referred to “opium poppy to include the plant *Papaver somniferum*, any other plant which is the source of opium or opium products, and any part of any such plant.” At the time, the law was misunderstood by farmers growing the plant for both floral and medical use in California, who believed that the signed legislation promoted the production of opium poppy for medical purposes in the United States, under close supervision of the Treasury and Agriculture Departments. The real purpose of the Act, in fact, was the exact opposite: not to promote production of the opium poppy but to curb it. The Narcotics Bureau replied to inquiries at the time as follows:

“The Opium Poppy Control Act, which was recently enacted, permits the licensing of opium poppy production only for the purpose of supplying the medical and scientific needs of the Nation for narcotic drugs. There is no immediate or presently prospective need for the growth of the opium poppy to supply medical and scientific needs, and, therefore, it is not now anticipated that any licenses will be issued.”⁴⁵⁹

Scientists had to analyse all variations of the plant and determined that those belonging to *Papaver Somniferum* (Holland Blue, Tall Paeony Flowered Double, Mikado Carnation, and Persian Poppy)

⁴⁵⁸ Senate Debates of the Union of South Africa, 10 May 1937, c. 1062.

⁴⁵⁹ United Nations Office of Drugs and Crime (UNODC) “*The Suppression of Poppy Cultivation in the United States*” 1950-01-01. See https://www.unodc.org/unodc/en/data-and-analysis/bulletin/bulletin_1950-01-01_3_page003.html (Date of use: 30 March 2019).

contained opium and had to be destroyed in their totality under the supervision of narcotic inspectors. Farmers were allowed to continue production of flowers and poppy seeds from other variations without the presence of opium (Flanders Poppy, American Legion Poppy, and the California Poppy). Through scientific analysis on all variations of the plant species, legislators were able to clarify the misinterpretations and promote more clear explanations.

Also, in the United States, the Drug Abuse Control Act of 1965 included dangerous drugs such as depressants (any quantity of barbituric acid or any of the salts of barbituric acid) and stimulants (any quantity of amphetamine, any of its optical isomers, or any salt of amphetamine). The definition of a depressant or stimulant drug, however, included the following significant language:

“Any drug which contains any quantity which the Secretary, after investigation, has found to have, and by regulation designates as having, a potential for abuse because of its depressant or stimulant effect on the central nervous system or its hallucinogenic effect”.⁴⁶⁰

The law excluded narcotic drugs such as opium, heroin and cocaine which were still covered by the Harrison Act.

5.2.2 *Increased legislation and law enforcement*

The start of the 1970s brought the biggest change and challenges for both law enforcement and forensic drug chemistry. New legislation in the United States created a wave of changes in other jurisdictions. The new legislation passed by Congress unified over fifty pieces of piecemeal legislation under one umbrella of control for narcotic and psychotropic drugs.⁴⁶¹ Soon after, other countries followed the initiative with similar legislation. Table 5.2 shows a comparison between this newly enacted legislation in the United States (US), and the United Kingdom (UK) and South Africa (SA).

⁴⁶⁰ Drug Abuse Control Amendments of 1965. Pub. L. No. 89-74, § 3a.

⁴⁶¹ Controlled Substances Act, 21 U.S.C. § 801 (2012); DEA History in Depth: 1970–1975, Drug Enforcement Admin. 9, <http://www.dea.gov/about/history/1970-1975.pdf> (Date of use: 30 March 2019).

Table 5.2 Legislative comparison of the 1970s drug acts of US, UK and SA.

	United States	United Kingdom	South Africa
Act Name	Comprehensive Drug Abuse and Control Act (1970) ⁴⁶²	Misuse of Drugs Act of 1971 ⁴⁶³	Abuse of Dependence-Producing Substances and Rehabilitation Centers Act of 1971 ⁴⁶⁴
Schedules	Schedule I,II, III, IV and V	Class A, B and C	Part I, II, III
Number of substances	+/- 150 (excluding their isomers, esters, ethers, salts, and salts of isomers, esters and ethers).	+/- 140 (excluding their stereo-isomeric form, esters, ethers, and salts).	+/- 140 (excluding their isomers, esters, ethers, salts, and salts of isomers, esters and ethers).
Cannabis language	"Marihuana" and "Tetrahydrocannabinols".	Cannabinol except where contained in cannabis or cannabis resin" and "cannabinol derivatives"	Cannabis (Dagga) and the whole plant or any portion or product thereof" and "Tetrahydrocannabinol".

After the 1970 enactment, the United States president declared an "all-out global war on the drug menace,"⁴⁶⁵ and established the Drug Enforcement Administration (DEA) to enforce the new Drug Act of 1970.⁴⁶⁶ The new law also empowered the DEA to schedule new drugs without Congressional approval once it was considered a dangerous drug.

⁴⁶² Comprehensive Drug Abuse and Control Act ch. 13 § 801 et seq. ch. 13 § 951 et seq., 1970.

⁴⁶³ Misuse of Drugs Act, 1971, § 25, ch. 38.

⁴⁶⁴ Abuse of Dependence-Producing Substances and Rehabilitation Centers Act 41 of 1971.

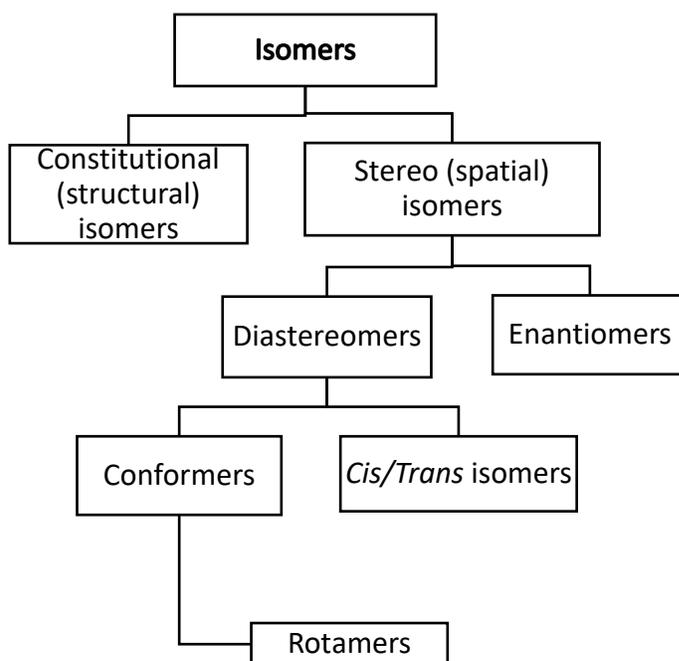
⁴⁶⁵ The President's message to the Congress transmitting reorganisation plan No 2 of 1973 to establish the *Drug Enforcement Administration 9 Weekly Comp Pres Doc 306 (1973-03-28)*.

⁴⁶⁶ Exec. Order No. 11,727, 38 Fed. Reg. 18,357 (July 6, 1973).

5.2.3 The isomer challenge

The Acts mentioned in Table 5.2 above placed a specific emphasis on law enforcement and an increase in drug analyses as the statutes contained more substances to be controlled with new descriptions and terminology, for example, referring to substances, their isomers, esters, ethers, and salts, as well as salts of isomers, esters, and ethers. The abovementioned laws, however, failed to define the term “isomer” or “stereo-isomeric” substances. What seems like a simple word for lawmakers, is actually a complicated one for scientists. A single substance such as cocaine has eight stereo isomers and when salts, esters, and ethers of isomers are included, a single substance can in the law have a number of chemical structures that the scientist should be able to identify. At that time, technology was not that advanced to enable forensic scientists to identify all the structural varieties. A breakdown of the word “isomer” is shown in Figure 5.1.

Figure 5.1 A breakdown of isomers



Most organic literature defines sub-groups of isomers and provides information on structural rules, which is hard to explain in layman terms in courts of law. It was, and still remains challenging for

forensic drug experts to explain in words the three-dimensional organic structural changes of “invisible” molecules that contribute to these isomers.

After a few years, the new language relating to isomers was challenged in the United States in the interesting case of *United States v. Bockius*.⁴⁶⁷ The petitioner, Robert Bockius, was charged with knowingly importing cocaine in violation of US import and distribution rules, by hiding 332.1 grams of white powder in his shoes.⁴⁶⁸ Bockius argued that he had S-cocaine (one of eight isomers of R-cocaine) in his possession and that the latter was not scheduled as a Schedule II narcotic controlled substance. Regardless of the fact that the defence admitted that it was an isomer (S-cocaine) of R-cocaine (naturally present in coca leaves) and therefore covered by the act, the judge requested Donald A. Cooper, the state expert, to perform additional analytical tests. Cooper conducted a polarimeter test (instrument that could measure optical rotation of compounds at multiple wavelengths) and concluded that it was indeed R-Cocaine and not the isomer S-Cocaine. The defendant first argued that the results of the test were delayed and not part of the discovery, and for that reason, his expert, Dr. Saphiro, did not have the opportunity to evaluate the results. The judge ordered the government to allow Dr. Saphiro access to the sample and instrumentation to conduct his own analysis, as it would only take twenty minutes according to the defence council.⁴⁶⁹ Dr. Saphiro came back and falsely claimed that it was indeed S-Cocaine. The trial jury did not believe the defence expert’s theory and results and convicted Bockius on both counts. It was unclear to follow the court’s reasoning, as the relevant prohibition referred to the listed substance (R-cocaine) or its isomers (S-cocaine, R-pseudococaine, R-allococaine, R-alloppseudococaine, S-pseudococaine, S-allococaine, and S-alloppseudococaine), or salts, ethers, or esters. This case set a disturbing precedent for future challenges on the cocaine debate. It was also later determined that the coca leaf only produces R-cocaine and that S-cocaine can only be synthesised through a more comprehensive knowledge of chemistry. Even then, a 50:50 ratio of R- and S-cocaine would be produced. Thereafter, the S-cocaine would have to be separated from the R-cocaine.⁴⁷⁰ The

⁴⁶⁷ *United States v. Bockius* 1977, 564 F. 2d 1193.

⁴⁶⁸ 21 U.S.C. § 952(a) and 960(a)(1) importation and 21 U.S.C. § 841(a)(1) distribution.

⁴⁶⁹ *Bockius* 1977 [11-17].

⁴⁷⁰ Baugh LD and Liu RH “Sample Differentiation: Cocaine Example” 1991 *Forensic Sci Rev Dec* 3(2):101-115.

method required a clear level of skill in the sciences and the low quantity yields were not worth all the effort to synthesise and separate.

In 2007, Congress passed the Positional Isomer clause to the Controlled Substances Act⁴⁷¹ to clarify the interpretation of positional isomers.

5.2.4 Regulating designer drugs and substances useful in their synthesis

With the rise of new and dangerous designer drugs, Congress passed the Comprehensive Crime Control Act in 1984,⁴⁷² to allow the Attorney General to fast-track uncontrolled substances' inclusion into Schedule I of the Act on an emergency basis. Even with the higher restrictions from the drug Acts, underground and "clandestine" chemists started experimenting with various chemicals in designing substances with different chemical structures that would mimic scheduled drugs with a higher potency than those controlled. Later in the 1980s, Henderson coined and added the name "designer drugs of abuse" to these substances.⁴⁷³ He assigned three characteristics to designer drugs: (1) they are synthesised from frequently available chemicals, and (2) due to their chemical structural change, they fall outside the scope of controlled substances, and (3) they are allocated exotic names when marketed. Fentanyl is one such an example where the chemical structure was altered, creating substance analogs with a potency 6,000 times that of morphine, which led to multiple death overdoses in the United States.⁴⁷⁴ After testimonies before Congress⁴⁷⁵ on how easy and profitable it was to produce these drugs, and also pointing to the gaps in previous legislation, the Controlled Substances Analogue Enforcement Act (CSAEA) was passed in 1986.⁴⁷⁶

⁴⁷¹ 21 CFR 1300.01(b) (21).

⁴⁷² Comprehensive Crime Control Act of 1984, Pub. L. No. 98-473, 98 Stat. 1976, [2071–72] (codified at 21 U.S.C. § 811 (2012)).

⁴⁷³ Henderson GL "Designer Drugs: Past History and Future Prospects" 1988 *J Forensic Sci* 569-570.

⁴⁷⁴ Jerrard DA "Designer Drugs: A Current Perspective" 1990 *J Emergency Med* 733.

⁴⁷⁵ *Designer Drugs: Hearing Before the S. Comm. on the Budget*, 99th Cong. 10 (1985) (statement of Hon. Charles Rangel, Chairman, Select Comm. on Narcotics Abuse and Control).

⁴⁷⁶ Controlled Substance Analogue Enforcement Act of 1986, Pub. L. No. 99-570, § 1203, 100 Stat. 3207, 3213–14.

According to the CSAEA, a designer drug is “a structural or functional analog of a controlled substance that has been designed to mimic the pharmacological effects of the original drug, while avoiding classification as illegal and/or detection in standard drug tests”. The Act’s intention was to prohibit the manufacturing of analogues of banned chemicals to produce legal drugs. To identify a substance to be an analog of a controlled substance, it had to meet three requirements:

- (1) it must be “substantially similar” to a listed controlled substance in Schedule I or II of Comprehensive Drug Abuse and Control Act (1970),⁴⁷⁷
- (2) have an effect on the central nervous system that is “substantially similar” to, or greater than, the controlled substance, and
- (3) the drug must be intended for human consumption.⁴⁷⁸

The statute tapped into two concepts that fell previously outside the scope of drug analysis, namely pharmacology (effect on central nervous system) and subjective reasoning (substantially similar), and considered each of these aspects as equally important. In the 1992 case of *United States v. Forbes*,⁴⁷⁹ the defendants contended that the definition of a controlled substance analogue as applied at the time, was unconstitutionally vague.⁴⁸⁰ Forbes distributed alphaethyltryptamine (AET), an uncontrolled substance, but with “substantially similar” chemical structure to dimethyltryptamine (DMT) and diethyltryptamine (DET), both schedule I substances. Two neuropharmacologists, Drs James Ruth and Charles Duncun, opposed the claim of substantial similarity and AET’s effect on the central nervous system. They also stated that the larger community of scientists would agree with their finding. One DEA chemist, Frank Sapienza, who disagreed with their statements, testified that the substance in question did have a substantially similar chemical structure, and with its structural tryptamine family root, would have some degree of hallucinogenic and stimulant activity. Another DEA chemist, Roger Ely, agreed with the defence experts, but based his opinion on the amine group (primary for AET versus tertiary amine

⁴⁷⁷ Controlled Substance Analogue Enforcement Act, 1986 § 802(32)(A)(i).

⁴⁷⁸ Controlled Substance Analogue Enforcement Act 1986 § 813.

⁴⁷⁹ *United States v. Forbes*, 806 F. Supp. 232, 238 (D. Colo. 1992) (“Congress declared that the purpose of the statute is to attack underground chemists who tinker with the molecules of controlled substances to create new drugs that are not yet illegal.”).

⁴⁸⁰ *United States v. Forbes*, 806 F. Supp. 232 (D. Colo. 1992), § 802(32) (A).

positioning for DMT and DET).⁴⁸¹ The court found that the definition of controlled substances analogue as applied to AET was unconstitutionally vague and did not provide fair warning or effective safeguards against enforcement. Forbes was hence not prosecuted.⁴⁸² Various other cases experienced similar language and terminology interpretation problems and caused many questions on both sides of the CSAEA.⁴⁸³

The circuit courts never addressed the language of “substantially similar” in the Act. The CSAEA had many flaws, which were uncovered years after its enactment. A report⁴⁸⁴ in 2012 noted that despite of the CSAEA and efforts from the DEA to control analogs of designer drugs, it is still theoretical possible to create hundreds of legal cathinones by tweaking their chemical composition. Similar to the cathinones was the synthetic cannabinoid epidemic, with more than 171 formulations and only five controlled by 2009.⁴⁸⁵ In 2015, Brown⁴⁸⁶ observed that courts did not hold manufacturers and distributors criminally liable for manufacturing substances that were not controlled, but rather focused on whether those substances posed the same health problems as the listed substance. The latter situation is different to what transpired in the case of *United States v. Lane*.⁴⁸⁷ Michael Lane synthesised “bath salts” (designer cathinones) in his garage, making up to \$8,000 a day through on-line sales.⁴⁸⁸ Colin Stratford, a biochemist working for Lane, testified that his employer (Lane) would monitor DEA legislation closely and determine which substances to manufacture that would fall outside of the ambit of the federal schedules.⁴⁸⁹ He also told the court that Lane would ask him to order “similar” chemicals (precursors) to those scheduled,

⁴⁸¹ *United States v. Forbes* 1992 [234].

⁴⁸² *United States v. Forbes* 1992 [239].

⁴⁸³ *United States v. Fisher*, 289 F.3d 1329, 1338 (11th Cir. 2002) (refusing to decide the issue); *United States v. Granberry*, 916 F.2d 1008, 1010 (5th Cir. 1990) (reciting the statute in the disjunctive without discussion). *United States v. Roberts*, 363 F.3d 118 (2d Cir. 2004).

⁴⁸⁴ Cameron KN et al. “Bath Salts: A Synthetic Cathinone Whose Two Major Components Act Similar to Methamphetamine and Cocaine on the Human Dopamine Transporter” 2012 *Biophysical J* 215a.

⁴⁸⁵ Advisory Council on the Misuse of Drugs “Consideration of the major Cannabinoid Agonists” 15–25 16th July 2009.

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/119149/acmd-report-agonists.pdf (Date of use: 3 April 2019).

⁴⁸⁶ Brown KE “Stranger than Fiction: Modern Designer Drugs and the Federal Controlled Substances Analogue Act” 2015 *Ariz St Law J* 47:449.

⁴⁸⁷ *United States v. Lane*, 2:12-cr-01419 (D. Ariz. 2013).

⁴⁸⁸ Hendley M “Eight Ballz Bath Salts” Maker Found Guilty by a Federal Jury” 2013-07-22 *Phoenix New Times*.

⁴⁸⁹ *Lane* 2013 [41-44].

although not banned themselves. One important piece of testimony was that of Stratford, who testified that when he and Lane discussed the CSAEA, Lane indicated if one follows the federal analogue act in a certain way, one should be able to “skirt the law”. The jury disagreed with this sentiment and Lane was found guilty and convicted under the CSAEA.

Due to an increased amount of methamphetamine, clandestine laboratories and users in the United States and globally, Congress enacted the Comprehensive Methamphetamine Control Act of 1996 (MCA).⁴⁹⁰ The Act related to the regulation of pseudoephedrine, phenylpropanolamine, and combination ephedrine drug products as List I chemicals, and the reporting of certain transactions involving pseudoephedrine, phenylpropanolamine, and combination ephedrine drug products. These chemicals were known as precursor chemicals (chemicals used in the manufacturing of methamphetamine).

Contrary to the position in the United States, instead of adding precursor chemicals in a separate act, the South African legislator decided to list these in Part II of the Drug and Drug Trafficking Act 140 of 1992.⁴⁹¹ The placement of precursors was first tested in its fullest extent in both a criminal and civil case in 2001 in South Africa. The National Director of Public Prosecutions (NDPP) brought an application for civil forfeiture under section 48(1) of the Prevention of Organised Crime Act (POCA), 121 of 1998.⁴⁹² Simon Prophet was first criminally charged for the importation of phenyl acetic acid, a controlled precursor substance in Part II, section 1 of Act 140 of 1992. A search warrant was obtained and his house was searched by the South African Narcotic Bureau and members of the National Forensic Science Laboratory. Experts from the laboratory discovered various chemicals, laboratory equipment and literature on the manufacturing of methamphetamine throughout the house, but no final product was discovered. Prophet’s defence team was able to get the criminal charges dismissed due to a technical wording problem within the search warrant, but the civil procedure led to a protracted legal battle right from the High Court in Cape Town⁴⁹³ to

⁴⁹⁰ 104th Congress of the United States, (S. 1965) enacted into law (PL 104-237), 1996.

⁴⁹¹ Drug and Drug Trafficking Act 140 of 1992, Vol. 329 No. 14143, Cape Town, 15 July 1992. *Government Gazette*.

⁴⁹² Prevention of Organised Crime Act (POCA), 121 of 1998, Vol. 402 No. 19553, Cape Town, 4 December 1998 *Government Gazette*.

⁴⁹³ The High Court of South Africa, Cape of Good Hope Provincial Division, Case No. 5926/01, 2003.

the Constitutional Court.⁴⁹⁴ The prosecuting authority had to prove that the premises of Prophet qualified as an “instrumentality”, where it was used as a means or an instrument in the commission of an offence. The scientific evidence and location thereof throughout the house was enough to place the burden of proof on the defendant to counter the claim of intent. The defendant failed in the Appellate Court and Constitutional Court to prove that his intention was not to manufacture methamphetamine and that he was merely experimenting with various chemicals. Prophet was evicted and his house and belongings were sold at auction. It was the first case in South Africa where a premises was identified as an “instrument” in the commission of an offense, based on the intent of manufacturing illegal substances.

5.2.5 Failure of regulations following the increase of drug addiction and new developments

As more substances were synthesised for both pharmaceutical and illegal markets in the late 1980s and early 1990s, methodologies had to be developed and validated for use in crime laboratories. Researchers had to keep up with all the new preparations developed and distributed to both the legal and illegal trade. In 2003, Klein and Hays published a paper in the *Microgram Journal*, titled “Detection and Analysis of Drugs of Forensic Interest”, which constituted a meta-analysis of literature review at the time.⁴⁹⁵ The study referenced 1377 journal articles and textbooks published during the period 1992 to 2001. A large number of the publications served as an aid to assist forensic drug chemists internationally with regard to scientific methodology and standardiation.

The study also revealed a large number of new drugs of abuse; including previously unknown “designer,” “analog” or “homolog” drugs, and also various pharmaceuticals or industrial chemicals which either had not been previously subject to abuse, or had been only rarely encountered in illicit settings. Klein and Hayes reported that although legislation and the enforcement thereof effectively controlled Lysergic Acid Diethylamide (LSD) internationally, new and more severe synthetic

⁴⁹⁴ *Simon Prophet v The National Director of Public Prosecutions*, Constitutional Court of South Africa, Case CCT 56/05, 2006.

⁴⁹⁵ Klein RFX and Hays PA “Detection and Analysis of Drugs of Forensic Interest” 2003 *Microgram J* 1(1-2):55.

hallucinogens such as tryptamines and dimethoxylated phenethylamines appeared on the illicit market. There was also an increase of hallucinogenic plants, such as psilocybin mushrooms and *Salvia divinorum*. An increase in the number of substituted amphetamines was also noted.

5.2.6 Developments into the 21st century

Going into the 21st century, governments, lawmakers, and forensic scientists faced enormous tasks with the increased amount of substances and the abuse of these. Pharmaceutical substance abuse was the fastest growing drug problem in the world. With the periodic listing of new designer substances, the list of controlled substances in acts increased, making drug prevention complicated. Besides the fact that law enforcement had surveillance on known groups of manufacturers and distributors, the internet became a new source of information for the ignorant pseudo-scientists who started to manufacture small quantities of drugs for their own recreational use. In addition, precursors, essential chemicals, and laboratory equipment were often sold on internet auction sites. This development stretched specialised drug enforcement to a point where more enforcement officers had to be trained on small-scale clandestine operations, as well as required internet monitoring that would lead drug enforcement officers to underground transactions and manufacturers. All of the imposed legislative sanctions did not decrease the number of drugs users, but instead forced these drug users and manufacturers to search for new and improved ways to make their own or designer drugs or new formulations falling outside of the scope of the law, as more people became increasingly familiar with the internet.

Another series of substances called Synthetic Cannabimimetics (synthetic cannabinoids) surfaced in the early 2000's, challenging legislation and drug chemists even more. Soon after their appearance, the DEA moved five synthetic cannabinoids into Schedule I under the temporary scheduling provision of the CSA, placing them in the same category as LSD, heroin, and cannabis.⁴⁹⁶ Despite federal and state regulations⁴⁹⁷ to prohibit their sale and distribution, the illicit use of these drugs continued.⁴⁹⁷ Besides the synthetic cannabinoids, synthetic stimulants (bath

⁴⁹⁶ News from DEA, Domestic Field Divisions, Washington DC News Releases, 24 November 2010 DEA Moves to Emergency Control Synthetic Marijuana 2013.

⁴⁹⁷ Bronstein AC *et al.* "Annual Report of the American Association of Poison Control Centers' National Poison Data System (NPDS)" *28th Annual Report 2011 Clin Toxicol (Phila)*; 49(10): 910–941.

salts), the beta-ketone amphetamine analogs, namely 3,4-methylenedioxy-N-methylcathinone (Methylone), 3,4-methylenedioxypyrovalerone (MDPV), and 4-methylmethcathinone (mephedrone) were also on the rise with new formulations reaching the market on a weekly basis.⁴⁹⁸ These beta-ketone amphetamine analogs are derivatives of cathinone. Although they produce stimulant effects similar to those of methamphetamine and methylenedioxymethamphetamine (MDMA),⁴⁹⁹ it was their hallucinogenic, paranoia, insomnia, agitation, and suicidal effects that were of greater concern for governing bodies and health authorities.⁵⁰⁰ These symptoms can mimic acute psychosis.⁵⁰¹ The problem was hence twofold: (1) the substances caused a dangerous threat to society at large, and (2) forensic scientists had to find new improved scientific methods to enable them to separate and identify these closely related structural compounds. Without these methods, drug chemists would not be able to structurally identify all the listed substances or misinterpret data of closely related analogs. Between 2008 and 2014, 142 synthetic cannabinoids were reported to the European Monitoring Centre for Drugs and Drug Addiction (EMCDDA).⁵⁰² To prevent the fast distribution of products containing synthetic cannabinoids, President Barack Obama signed the Synthetic Drug Abuse Prevention Act of 2012⁵⁰³ on July 10, 2012 into law. It banned synthetic compounds commonly found in synthetic cannabinoids and “bath salts”, placing them under Schedule I of the Controlled Substances Act.

5.2.7 Regulation of abused substances as a recurring cycle

A historical overview of legislation on abused substances makes it clear that the “catching-up” strategy by legislators over time has had limited success. Historically, the legal process followed throughout the last century may be described as a recurring cycle consisting of the following:

⁴⁹⁸ Gershman JA and Fass AD “Synthetic cathinones ('bath salts'): legal and health care challenges” 2012 *P & T: Peer-reviewed JI for Formulary Management* 37 (10):571–595.

⁴⁹⁹ Smith C *et al.* “Bath salts as a ‘legal high’” 2011 *Am J Med* 124(11).

⁵⁰⁰ Fass JA *et al.* “Synthetic cathinones (bath salts): legal status and patterns of abuse” 2012 *Ann Pharmacother* 46(3):436–441.

⁵⁰¹ Mugele J *et al.* “Serotonin syndrome associated with MDPV use: a case report” 2012 *Ann Emerg Med* 60(1):100–102.

⁵⁰² Abouchedid, R *et al.* “Acute Toxicity Associated with Use of 5F-Derivations of Synthetic Cannabinoid Receptor Agonists with Analytical Confirmation” 2016 *J Med Tox* 12(4):396–401.

⁵⁰³ 112th Congress (2011-2012): Synthetic Drug Abuse Prevention Act of 2012, S.3190.

- a naturally occurring or synthesised substance with either a psychological or physical dependence or both would be abused;
- laws would then be drafted and enacted to protect society from the dangers of that substance;
- law enforcement would enforce an Act;
- forensic scientists would develop a methodology that would enable them to structurally identify those substances; and
- clandestine operators would monitor the structural identity of controlled substances within those Acts and then synthesise similar substances that would mimic and/or enhance effects of those listed substances.

The process will repeat itself unless regulations are changed that will break the “catching-up” cycle. Possible solutions to address this problem are discussed later within this chapter.

The next section will provide an overview on scientific method developments relating to controlled substance regulation and how it was applied in drug analysis to support prosecution within the criminal justice process.

5.3 Introduction and early development of scientific methodology

Most of the scientific methodologies relating to the regulation of controlled substances were not developed within the forensic drug community, but rather adopted from external communities and applied within forensic science. Europe particularly, during the Industrial Revolution, was seen as “the brightest heaven of inventions” and was known for providing scientific tools to solve crimes. Most of these inventions were related to the field of Physics and Chemistry.⁵⁰⁴ It was the German, Wilhelm Ostwald, who published a book in 1884⁵⁰⁵ on the scientific fundamentals of analytical chemistry and took the lead on discoveries in substance identification. Laitinen was regarded as the pioneer of scientific analytical chemistry. In his book on the history of analytical chemistry, he writes as follows on the state of analytical chemistry:

⁵⁰⁴ Tilstone “History, methods, and techniques” 2006.

⁵⁰⁵ Ostwald W *Lehrbuch der Allgemeinen Chemie* (Translated as: Textbook of general chemistry) in 1884.

“Analytical chemistry, or the art of recognizing different substances and determining their constituents, takes a prominent position among the applications of the science, since the questions it enables one to answer arise wherever chemical processes are employed for scientific or technical purposes. Its supreme importance has caused it to be assiduously cultivated from a very early period in the history of chemistry, and records comprise a large part of the quantitative work which is spread over the whole domain of the science.”⁵⁰⁶

It is trite that science is the study of quantitative relationships and that the interpretation of the data generated in scientific analysis would require more quantitative measurements.⁵⁰⁷ It was the latter part of the previous statement which became neglected in the forensic sciences. Many other scientists continued the work of the German chemist, Wilhelm Ostwald (1853 – 1932) into the 20th century, enhancing the fundamental nature of quantitative analysis in science.⁵⁰⁸

It was the study of organic compound analysis that laid the foundation of forensic drug analysis. Shriner and Fuson⁵⁰⁹ were two of the most prominent scientists that used quantitative methods, such as saponification and neutralisation which identified esters, acids, and bases. In 1947, Siggia, was the first scientist to adopt the term “functional group”. He subsequently published a work, titled “Quantitative organic analysis via Functional groups”.⁵¹⁰

5.3.1 Early scientific discoveries

As technology developed, organic compound identification evolved into systematic methodological approaches and modern organic structural identification of millions of organic compounds. The early years of forensic drug science focused on qualitative analysis (detection and identification of the constituents of a sample) which entailed the separation of controlled substances through sample precipitation, extraction, or distillation, followed by chemical treatments to yield products that could be recognised by odour, colour, boiling or melting points, solubility in a series of solvents,

⁵⁰⁶ Laitinen HA and Ewing GW *A history of analytical chemistry* (The Division of Analytical Chemistry of the American Chemical Society York PA 1977).

⁵⁰⁷ Laitinen “Analytical chemistry” 1977.

⁵⁰⁸ The works of Boyle, Priestley, Lavoisier, Scheele, Dalton, Davy, Gay-Lussac, and Berzelius.

⁵⁰⁹ Shriner RL *et al. The Systematic Identification of Organic Compounds* (John Wiley & Sons INC 8th ed 2004).

⁵¹⁰ Siggia S *Quantitative organic analysis via Functional groups* (John Wiley & Sons INC 1st ed 1949).

optical activities, or reflective indices. It was followed by quantitative analysis through gravimetric or titrimetric measurements to determine the amount of constituents present in a sample mixture.⁵¹¹ These concepts did not change and stayed the same until today. However, it is the instrumental development that added multiple chemical techniques that are applied to the analysis. Table 5.3 below summarises scientific discoveries that led to instrumental developments which are applied in forensic drug chemistry today.⁵¹²

Table 5.3 Scientific discoveries contributed to Instrumental development applied in forensic drug laboratories.

Technique	Discoverer	Discovery
Analytical Spectroscopy	Sir Newton (1666)	Origin of absorption spectra through radiation
	Sir Herschel (1800)	Discovered the existence of Infrared Spectroscopy (IR).
	Ritter (1800)	Discovered more invisible light on the violet side (Ultraviolet (UV) radiation).
	Wollaston (1802)	Identified dark lines in solar spectrum.
	Von Fraunhofer (1812)	Studied the dark lines using a spectroscope.
	Beer (1853)	Recognised the relationship between the absorption of light and concentration. (Beer-Lambert Law).
	Kirchhoff and Bunsen (1859)	Observed different colors from elements heated to incandescence.
	Angstrom (1868)	Measured the wavelengths of about 1,000 Fraunhofer lines.
	Abney and Festing (1882)	Obtained infrared absorption spectra for over 50 compounds.
Molecular Spectroscopy (UV Spectroscopy)	Henri (1919)	Investigated Organic Compounds instrumentally.

⁵¹¹ Skoog "Instrumental Analysis" 1992.

⁵¹² Laitinen "Analytical Chemistry" 1977.

	Beckman (1941)	Developed the first commercially viable scientific instrument for measuring the amount of ultraviolet light absorbed by a substance.
Vibrational Spectroscopy (IR & Raman Spectroscopy)	Perkin-Elmer corp. (1944)	Introduced a single beam IR spectrometer.
	Dow group (1946)	Introduced a double beam IR spectrometer (plot transmission against wavelength).
	Rank and Wiegand (1946)	Described first Raman grating spectrometer with photoelectric detection.
	Fellgett (1949)	Calculated a spectrum from an interferogram using numerical Fourier transform infrared (FTIR).
	Porto and Wood (1962)	Introduced the use of a pulsed ruby laser for exciting Raman spectra.
Spectropolarimetry	Biot (1818)	Observed that organic compounds had the property of rotating the plane of polarised light.
	Pasteur (1848)	Discovered that organic crystals appeared to be mirror images of others (Isomers).
	Bell and van't Hoff (1874)	When plane polarised light transverses an optical active medium, the right and left circularly polarized components travel at different speeds (<i>d, l</i> or <i>R, S</i> optical rotary dispersion).
	Rudolph (1953)	Developed the first commercial photoelectric spectropolarimeter to measure optical rotation of compounds at multiple wavelengths.
Nuclear magnetic resonance (NMR)	Faraday (1845)	Discovered that interaction is possible between radiant energy and magnetic fields.
	Zeeman (1896)	Described the splitting of emission lines of atoms by a magnetic field. Electrons must possess a spin.

	Arnold (1951)	Discovered the first spectra that showed separate resonances for the hydrogen nuclei in different locations in the same molecule.
	Shaw and Elsken (1955)	Determined of the total number of hydrogen atoms in organic liquids.
Mass spectrometry (MS)	Sir Thomson (1898)	Developed a device to analyse positive rays in a discharge when bent by electric or magnetic fields.
	Aston (1919)	Focused ions on a plane to give a spectrum of ion masses. (Also used for isotope studies).
	Bleakney (1932)	Developed a 180 degree magnetic deflection instrument for isotope abundance measurements, electron impact studies, and gas analysis by MS.
	Nier (1936)	Built larger instrument to study fragmentation of relatively heavy hydrocarbons by electron impact. Produced first reliable mass spectrum of benzene.
Fragmentation Patterns (MS)	Washburn, Wiley, Rock and Berry (1945)	Developed rules for aliphatic hydrocarbon fragmentation of organic compounds.
	O'Neal and Weir (1951)	Introduced heated inlets and reservoirs increase the analysis of volatile hydrocarbons and more polar types.
	McLafferty (1956)	Explained that concepts used to explain reaction mechanisms of organic compounds in solution could also be applied to fragmentation in the mass spectrometer.
Thin layer Chromatography	Beyerinck (1889)	Diffused hydrochloric acid and sulfuric acid through a thin layer of gelatin.
	Kirchner (1954)	Introduced quantitative thin layer chromatography.

Electrophoresis	Reuss (1808)	Observed that when an electrical field is imposed across a fluid suspension of charged particles, the particles migrate towards the pole that bears the opposite charge, called "electromigration".
	Hardy (1899)	Migration of particles based on pH phases. Determined isoelectric point near neutrality.
	Tiselius (1930)	Developed first sophisticated apparatus which used reversible electrodes, temperature control and observation of movement of proteins using UV light.
	Davis and Ornstein (1959)	Introduction of synthetic polyacrylamide gels. Ability to separate molecules based on size and mobility, which provides reliable means for measuring molecular constants, such as molecular weight, Einstein-Stokes radii, and electrophoretic mobilities.
Liquid Chromatography	Tswett (1910)	Published more than 50 papers and a book on chromatography and pigments.
	Hamilton (1960)	Introduced high-performance liquid chromatography (LC) in the analysis of amino acids.
Gas Chromatography	Hesse et al. (1941)	Used gas adsorption to separate volatile organic acids.
	Cremer (1944)	Determined that compounds can be separated by a chromatographic process in the gas phase and the adsorption energies be calculated from the elution times.
	Cremer (1946)	Separated mixtures using a column filled with silica gel, using hydrogen as a carrier gas and a thermal conductivity detector. Also introduced the idea of relative retention times,

		determination of peak area, and importance of logarithms.
Gas-liquid partition chromatography	Martin and Synge (1941)	Used liquid-liquid partition as basis of chromatography. Gas can be used as mobile phase instead of a liquid.
	Martin and James (1951/52)	Used 1-3 meter columns with 4mm id filled with inert porous particles coated with a liquid phase to separate compounds by titration.
	Horvath (1963)	Developed the first support coated open-tubular column.
Gas Chromatography-Mass Spectrometry	Holmes and Morrell (1957) also Donner, Johns and Gallaway (1957)	Introduced the combination of gas chromatography with affluent monitoring by a mass spectrometer.
	Dal Nogare (1960)	Introduced temperature programming to reduce the elution times of high boiling compounds.

Table summary above based on "A History of Analytical Chemistry", 1977.⁵¹³

The identification methodology of organic molecules for drug identification can be divided into three developmental phases: (1) the establishment of colour tests to notice similarity of colour reactions between the unknown sample and a known reagent, (2) a separation technique, known as chromatography, which enables scientists to separate multiple organic compounds before identification based on chemical and physical properties, and (3) mass spectrometry, where chemical substances can be identified based on their chemical structures.

Throughout time, legislators developed new laws and added new controlled substances; and analytical chemists in law enforcement explored technologies to enable them to identify the various compounds listed. International networks between forensic drug scientists were limited, and these analytical changes and breakthroughs had to be conveyed nationally and internationally to forensic crime laboratories.

⁵¹³ Laitinen *Analytical Chemistry* 1977.

5.3.2 Application of scientific methodology in forensic settings

In 1967, the Bureau of Drug Abuse Control started with their first publication of the “*Micro-gram*”, containing informative articles on discoveries made in their US laboratories. It served multiple purposes as a journal, technical note and news medium.⁵¹⁴ It also provided training opportunities for local and state police chemists in the United States and later internationally. Early publications addressed methodological discoveries in colour, “spot” tests, melting points, ultra-violet absorption spectra, and infrared absorption spectra.⁵¹⁵ Due to alarming increases globally both in the frequency and volume of seized drugs such as opiates, cocaine, cannabis, and other synthetic drugs, forensic drug laboratories were faced with enormous challenges. Underground chemists unfortunately continuously produced new illicit narcotic drugs or combination of drugs before distributing these on the illicit market.

The growth in illicit substances required fast and effective action, as well as ingenuity on the part of forensic scientists. The increase in the number of new drugs led to more substance control regulations which placed additional pressure on forensic drug chemists internationally to use rapid, more precise, and more specific methodology for structural identification of unknown substances. National and international authorities had to be informed of new trends and analytical data had to be disseminated soon after discoveries were made. Also, the exchange of analytical data internationally required the use of globally acceptable methods of testing.

In February 1984, the Commission on Narcotic Drugs requested the Secretary-General of the United Nations “to investigate the possibility of reaching agreement at the regional and interregional levels of recommended methods of analysis of drugs seized from the traffic”. In response to the Commission’s request, a group of fifteen experts was convened in October 1985 by the Division of Narcotic Drugs in Wiesbaden, Germany, to develop recommended methods for testing

⁵¹⁴ DEA Microgram Examples of first publications <https://erowid.org/library/periodicals/microgram/> (Date of use: 31 January 2019).

⁵¹⁵ Bureau of Drug Abuse Control 1967. https://erowid.org/library/periodicals/microgram/microgram_1967_11_v01n01.pdf (Date of use: 31 January 2019).

controlled substances.⁵¹⁶ The first published manual by the United Nations in 1986 was on recommended methods for testing heroin. This was followed by an array of recommended methods for other controlled substances such as cocaine, opium/crude morphine, illicit ring-substituted amphetamine derivatives, etc.⁵¹⁷ Knowledge of analytical methodology became more important because the use and abuse of controlled substances were not only confined to developed countries, but also squandered to developing countries. Developing countries required internationally recognised methods to keep up with global case prosecutions. After their meeting in November 1992, the United Nations Drug Control Program published new recommendations on quality assurance and Good Laboratory Practices (GLP) in analytical schemes to be implemented by international drug laboratories.⁵¹⁸

Both the Bureau of Drug Abuse Control and the United Nations Drug Control Program provided a foundational platform for forensic chemists to use and testify on methods that were internationally acceptable.

5.3.3 The value of early scientific methods

Over time, applied methods showed repeatability and that they were fit for the intended purpose. These followed the rule of Kuhn on falsifiability (e.g. that scientists never reject a scientific paradigm without simultaneously accepting a new paradigm, especially on spontaneous- and implicit discoveries)⁵¹⁹ and were applied in case samples as valuable method-solving techniques. With continuous testing of various listed and non-listed substances (substances similar in chemical reactivity showed the same colour reactions), particular processes that demonstrated repeatability for years and indicated continuous specific results, changed unexpectedly when the same results appeared for different analytes (substances with similar reaction properties, but different chemical structures) while using a specific method. Methods such as colour “spot” tests lost their evidential value and were no longer fit for the intended purpose to identify a specific drug, but rather a series of compounds with similar chemical properties, either controlled or non-controlled.

⁵¹⁶ United Nations Office on Drugs and Crime, (UN, ST/NAR/6, 1986).

⁵¹⁷ United Nations Office on Drugs and Crime (UN, ST/NAR/7, 9, 10, 11, 1987).

⁵¹⁸ United Nations Office on Drugs and Crime (UNDCP: ST/NAR/26:1995).

⁵¹⁹ Stone MA “A Kuhnian Model of Falsifiability” 1991 *The Brit J Phil Sci* 42:177-185.

The scientific method was applied to identify a chemical substance based on its physical appearance and chemical reactivity to qualify the substance in question, but at this point in time there were clearly limitations with regard to certain colour tests.⁵²⁰ These methods could no longer be used as a confirmatory test for a substance, but only as a method to indicate the presence or absence of a specific functional group or class in a questioned sample.

One such example was from the creation of a chemical mixture that could identify the presence of cocaine in street samples by L.J. Scott, Jr., a chemist at the DEA, in 1973.⁵²¹ This happened at a time when the trafficking and use of cocaine were exploding and federal and local authorities wanted a solution to stop or limit the problem as quickly as possible. The DEA wanted something that was cost-effective and convenient to use, and legally authoritative.

This newly discovered Cobalt (II) thiocyanate colour test, better known as the Scott's test,⁵²² became part of drug test kits that agents and officers could carry with them. Scott validated the test over nine months before rolling it out — first in the DEA's laboratories and then with detectives in the field — before declaring success. He wrote in an internal DEA memorandum that the method proposed is almost impossible to misinterpret, and that the test is highly sensitive and specific.⁵²³

Only weeks after Scott declared success, arrests were made based on the tests' results. In less than a decade after "Scott's test", at least 12 brands of testing kits surfaced, which could test not only for cocaine, but also a variety of other illegal drugs. Police departments across the country purchased and used these testing kits by the thousands.

⁵²⁰ Tilstone "History, methods, and techniques" 2006.

⁵²¹ Scott LJ, Jr. "Specific field test for cocaine" 1973 *Microgram J* 6 179-181.

⁵²² Scott "Cocaine" 1973.

⁵²³ Gabrielson R "Meet the chemist behind many popular—and faulty—police drug kits" 2016-07-22
Pacific Standard Staff.

The test was later modified by Fansello and Higgins in 1986,⁵²⁴ to make it even more specific for cocaine identification, but adulterants and diluents were added to the drug before sold on streets, which led to false positives in some cases.⁵²⁵

While some methods lost scientific value, other became more discriminatory when analysing organic compounds. Crime laboratories had different analytical approaches when analysing unknown street samples, which posed a challenge for drug chemists in expert testimony, especially when different values were given in testimony to the same analytical method. This issue had to be addressed through standardisation, discussed next.

5.3.4 Establishment of standardised recommended methods for drug analysis

In 1997, the United States Drug Enforcement Administration (DEA) and the Office of National Drug Control Policy (ONDCP) co-sponsored the formation of the Technical Working Group for the analysis of seized drugs (TWGDRUG), later named Scientific Working Group for the analysis of seized drugs (SWGDRUG).⁵²⁶ Forensic drug chemists around the globe, representatives of the United Nations, several international organisations and academics met in 1999 in Washington DC to develop recommendations for educating forensic practitioners in the analysis of seized drugs. By setting these recommendations, developed methodologies and instrumentation would be assigned the same evidential value in expert testimony. The working group categorised analytical techniques according to their discriminatory value. Techniques incorporated within the analytical scheme can be classified into three categories based upon the level of selectivity they achieve. An appropriate analytical scheme shall achieve a sufficient level of selectivity to enable a scientifically supported conclusion relevant to the jurisdiction and laboratory protocols. Figure 5.2 below provide the level of selectivity.

⁵²⁴ Fasanello J and Higgins P "Modified Scott test for cocaine" 1986 *Microgram J* 19:137-138.

⁵²⁵ Hooper R "On-the-spot coke test flaws are exposed" 2005 *New Sci* 12:188.

⁵²⁶ Standard Working Group for Drugs (SWGDRUG) "*Methods of analysis/analytical scheme for identification of drugs or chemicals*" Part IIIB Version 8, June 2019.
http://www.swgdrug.org/Documents/SWGDRUG%20Recommendations%20Version%208_FINAL_ForPosting_092919.pdf (Date of use: 10 January 2020).

Figure 5.2 Level of selectivity in Analytical scheme⁵²⁷

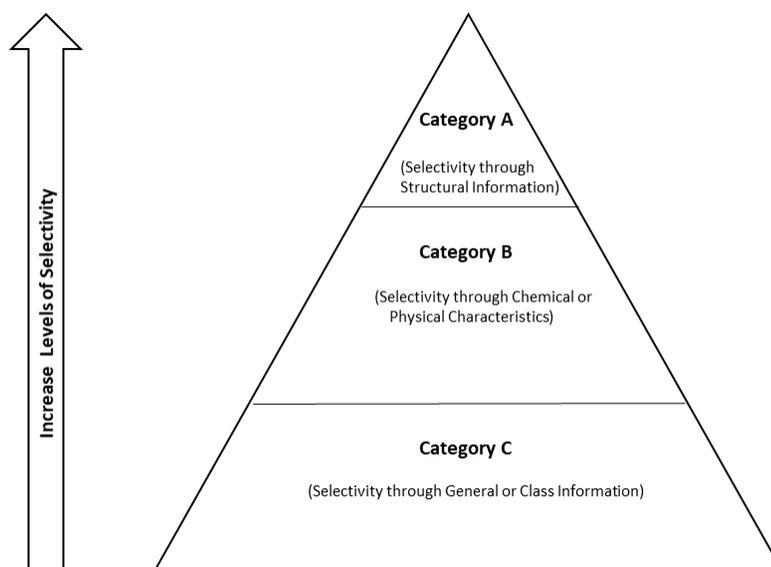


Table 5.4 below lists the techniques according to strength and limitations that could affect the design of a validation plan.

Table 5.4: Table of technique categories

Category A	Category B		Category C
Infrared spectroscopy	Capillary electrophoresis	Microcrystalline tests	Colour tests
Mass spectrometry	Gas chromatography	Ultraviolet/Visible Spectroscopy	Fluorescence spectroscopy
Nuclear magnetic resonance spectroscopy	Ion mobility spectrometry	Thin layer chromatography	Immunoassay
Raman spectroscopy	Liquid chromatography	Cannabis-macroscopic/microscopic examinations	Melting points
X-ray Diffractometry	Supercritical Fluid Chromatography	---	Ultraviolet spectroscopy

Adapted from SWGDRUG Analytical Techniques.⁵²⁸

⁵²⁷ SWGDRUG *Methods* 2019 [14].

⁵²⁸ SWGDRUG *Methods* 2019 [15].

It was a pro-active move by the organisation to provide not only guidance to drug chemists to follow analytical schemes in identifying controlled substances, but also to assist courts with minimum standard practices that should be used before admitting analytical reports in court trials. If crime laboratories followed these analytical schemes and courts would only allow these as the only acceptable procedures for positive identification, fewer problems would have been encountered during criminal procedures.

Unfortunately, courts did not follow the recommendations and years after the first flaws were exposed with regard to colour tests, law enforcement officers continued to use these spot tests when pulling over suspected individuals in vehicles. In July 2016, *ProPublica*, an independent, non-profit newsroom that produces investigative journalism in the public interest, wrote that “decades after L.J. Scott developed a test for cocaine, his invention played a role in hundreds of wrongful convictions of scores of people in Houston.”⁵²⁹ The tests had either registered false positives or had been misinterpreted by the officers using them. The wrongly accused pleaded guilty after notification by the officers of the results. Convictions were handed down before forensic laboratory reports reached the prosecution, which presented a legal failure and not a forensic evidence failure. Many of those reports came back negative from the crime laboratory and were often filed without notification or exoneration of the convicted individuals. After discovery of the lack of attention given to the reports, the national registry of exonerations and the media placed the blame on false or misleading forensic evidence.⁵³⁰ Regrettably, this could have been avoided if the courts waited for the confirmatory laboratory reports and not relied on spot tests alone for

⁵²⁹ Gabrielson R “No Field Test is Fail Safe’: Meet the Chemist behind Houston’s Police Drug Kits” 2016-07-11 ProPublica. <https://www.propublica.org/article/no-field-test-is-fail-safe-meet-the-chemist-behind-houston-police-drug-kits> (Date of use: 22 February 2018).

⁵³⁰ The National registry of exonerations “A Project of the University of California Irvine Newkirk Center for Science & Society, University of Michigan Law School & Michigan State University College of Law” <http://www.law.umich.edu/special/exoneration/Pages/browse.aspx> (Date of use: 11 January 2020).

Examples were that of, Texas arrested 52-year-old Johnny Adams after they confiscated a substance that field-tested positive for cocaine.

On August 3, 2010, police in Houston, Texas pulled over a car driven by Anthony Wilson, who had traveled to Houston from Monroe, Louisiana, for a job interview. Amy Albritton, an occupant and owner of the car was arrested on a charge of possession of a controlled substance.

On June 12, 2009, police in Houston, Texas arrested 38-year-old Earl Amory after they seized a substance from him that field-tested positive for the presence of cocaine.

conviction. As many of these spot tests were distributed and used internationally and the problem was uncovered in only one state in the United States, it is not inconceivable that similar incidents happened elsewhere. Many individuals could have received a criminal record for possession of a controlled substance that is technically *not* a controlled substance. It could take years of audits to uncover all these cases for those innocently convicted, and there is no guarantee that these audits will be conducted.

The National Institute of Justice never denounced the use of colour tests, but acknowledged that the overall use was still valid, repeatable, reliable, but with limitations on specificity.⁵³¹ Despite the fact that its discriminatory value decreased, it remained a quick and inexpensive method with valuable contributions within forensic science laboratories, if deployed as a screening method and not a confirmation, test.

Colour tests have a low level of uncertainty during sample preparation, due to the larger amounts of samples used, limiting the effect of trace cross-contamination with smaller sample amounts.⁵³² When the presence of components with the same characteristics of a specific drug or substance is determined by this preliminary technique, the scientists have protocols in place to direct them to which solvent and analytical method to use to confirm results with higher accuracy.

5.3.5 Dynamic change in analytical methodology

One of the most dynamic changes for forensic drug chemistry and toxicology occurred in the late 1960s and early 1970s when two previously well-known methods, namely gas chromatography (GC) and mass spectrometry (MS) were combined by the advent of carrier gas separators that removed the GC carrier gas prior to the introduction of a sample into the high-vacuum mass spectrometer.⁵³³ An ionisation chamber at the inlet turns the separated compounds into charged

⁵³¹ National Institute of Justice “*Color Test Reagents/Kits for Preliminary Identification of Drugs of Abuse*” NIJ Standard–0604.01 July 2000.

⁵³² O'Neal CL *et al.* “Validation of Twelve Chemical Spot Tests for the Detection of Drugs of Abuse” 2013 *Encyc Forensic Sci* 380-387.

⁵³³ Separators were developed independently by Einar Stenhagen (then at Uppsala University, later at Gothenburg University, Sweden); Ragnar Ryhage of the Karolinska Institute, Stockholm; and Biemann.

ions, by removing one electron from the analyte. The ions are then accelerated in a mass analyser and separated from one another using a magnetic field, which deflects the ions based on their masses. After separation, the ions enter a detector, which in turn generates an electric signal proportional to the number of ions striking it. This creates a mass spectrum that shows the mass-to-charge ratio of the fragments of the compound coming from the sample. The mass spectrum can then be compared to mass spectral libraries or to reference standards ran under the same conditions. By 1973, the Home Office Central Research Establishment in Birmingham in the United Kingdom indicated 179 types of cases within 10 different forensic applications that utilised Gas Chromatography Mass Spectrometry (GC-MS) for results.

In 1973, a *Wisconsin Law Review*⁵³⁴ revealed in a survey of 100 crime laboratories that only two of the laboratories had GC-MS instruments and nine indicated a need for one. The use of standardised methods and instrumentation was confirmed by the survey study of Venter,⁵³⁵ conducted over the period 2005 to 2007. This study, titled “International benchmarking of quality management in forensic science drug laboratories”, involved a total of 70 international laboratories across 27 of the 50 states of the United States of America, Canada, Australia, New Zealand, Belgium, Finland, Netherlands, Switzerland, Taiwan, Israel and South Africa. Table 5.5 below, based on Venter’s survey results, depicts the most utilised methodologies internationally in forensic drug laboratories.

Table 5.5 Analytical techniques used in international forensic drug laboratories

Technique	Purpose summary	A - (%) Laboratories indicating yes	B - 95% CI ^a
Colour tests	<ul style="list-style-type: none"> Indicates presence or absence of a certain drug type in a non-extracted sample. Positive result indicates a certain class of drugs. 	98.6 (n = 70)	95.8 – 100.0
Thin Layer Chromatography (TLC)	<ul style="list-style-type: none"> Quick separation and comparison technique Indicates probable identity of analyte and probable presence of additional compounds Also useful as a preparative method 	78.6 (n = 70)	69.0 - 88.2

⁵³⁴ Zoro JA and Handley K “Organic Mass Spectrometry in Forensic Science” 1976 *J Forensic Sci Soc* 16(2):103-114.

⁵³⁵ Venter CH “International benchmarking of quality management in Forensic science drug laboratories” (MSc thesis North West University South Africa 2010).

Technique	Purpose summary	A - (%) Laboratories indicating yes	B - 95% CI ^a
Microcrystalline tests	<ul style="list-style-type: none"> Determining the presence of many chemicals including both controlled and other related compounds Differentiation of closely related analogues 	40.0 (<i>n</i> = 70)	38.5 – 51.5
Gas Chromatography (GC)	<ul style="list-style-type: none"> The same as TLC but with a higher level of discrimination. Quantitative analysis of known compounds. 	80.0 (<i>n</i> = 70)	71.6 – 89.4
High-Performance Liquid Chromatography (HPLC)	<ul style="list-style-type: none"> The same as GC but a non-destructive method Terminal labile drugs can be analysed Non-volatile drugs can be analysed without derivatisation Quantitative analysis with great selectivity Separate enantiomers by using chiral columns 	42.9 (<i>n</i> = 70)	31.3 – 54.5
Raman Spectroscopy	<ul style="list-style-type: none"> Yields structural information that provides sufficient selectivity High purity substances and concentrations are necessary Isomer discrimination ability 	10.0 (<i>n</i> = 70)	3.0 – 17.0
Infrared Spectroscopy (IR)	<ul style="list-style-type: none"> The same as Raman but with a higher discrimination Discriminates between diastereomers, free base/acid and salt forms Non-destructive method 	87.1 (<i>n</i> = 70)	79.2 – 95.0
Mass Spectrometry (MS)	<ul style="list-style-type: none"> Discrimination between diastereomers Mass spectrum yields structural information with high discrimination capability Hyphenation with GC and LC able to identify several compounds in the same sample Also multidimensional MS techniques 	100.0 (<i>n</i> = 70)	100.0

a = the percentages indicated in the last column are based on a 95% confidence interval. *n* = total number of laboratories that answered the specific question.

Table 5.5 shows that colour tests and TLC were continued to be used as the methods of choice in forensic drug laboratories during the period surveyed for the preliminary inclusion or exclusion of drug groups. This is due to their rapid and inexpensive qualities, while making a valuable contribution to the analytical scheme. The survey determined that the confirmatory tests of choice in forensic drug laboratories were FTIR and GC-MS. Both have a high discrimination capability and, with the correctly selected sample preparation, majority of organic compounds can be structurally identified. With more sophisticated instrumentation, less sample amounts are necessary, which in turn may increase the uncertainty levels during sample preparation, as higher

risks of cross contamination are possible. The combination of GC and MS led to other combinations as well, such as liquid chromatography (LC) detectors, which enabled forensic toxicologists and chemists to separate and identify chemical structures of controlled substances, toxins, fires, and explosives. With the increased amount of designer drugs, better resolution was needed to distinguish between them, and researchers/vendors added a second mass separator (GC/MS/MS) to accomplish those resolutions. Tandem LC/MS techniques (HPLC/MS, CE/MS, UHPLC/MS) and tandem LC-MS/MS techniques, enabled mass spectral analyses of thermally sensitive compounds that do not survive heated injection ports.

Other enhancements in the early 2000's was the use of Inductively Coupled Plasma Mass Spectrometry (ICP-MS) for drug profiling, such as geographical sourcing of cocaine and heroin (the identification of trace compounds in samples provides information about the geographical area where plants were grown and cultivated), and synthetic route determination of amphetamine type stimulants. Through these profiling capabilities, law enforcement is able to monitor and track developing trends in production and trafficking of controlled substances.

Since the inception of mass spectrometry in forensic drug laboratories, little to no attention was given to challenging the interpretation of mass spectra from a legal perspective. Two possible reasons for this are: (1) legal professionals are unfamiliar with the concept and that these are too technical to address in court, and (2) the expenses for hiring a forensic expert may not worth the penalty or sanction associated with the offense, specifically in cases of possession of illicit drugs.

Similar to fingerprint comparison or electropherograms in DNA analysis, interpreting the data from a mass spectrum is basically a subjective procedure. The scientist compares the mass spectrum of the unknown sample to either an electronic library mass spectrum or to a known reference (positive control) mass spectrum.^{536,537} The library search algorithm provides a list of the closest

⁵³⁶ Hertz HS *et al.* "Identification of mass spectra by computer-searching a file of known spectra" 1971 *Anal Chem* 43: 6:681-691.

⁵³⁷ Stein SE "Mass Spectral Reference Libraries: An Ever-Expanding Resource of Chemical Identification" 2012 *Anal Chem* 84:7274-7282.

matching spectra by structural similarity to the unknown spectra.^{538,539,540,541,542} However, the increased frequency of new designer drugs and analogs presents a drawback regarding the use of search libraries. If a mass spectrum of a known substance is not present in the library, it is nearly impossible to identify the unknown substance. An interpretative power is then needed by some mass spectra database systems, to create a structure similarity that will give enough information about the unknown. Demuth *et al.*⁵⁴³ identified the following three approaches for interpretative library search systems which contributed to this field:

(1) McLafferty and co-workers developed a self-training and interpretative retrieval system,⁵⁴⁴ predicting characteristic sub-structures in the unknown after resulting search lists were generated;

(2) Using a SISCOM algorithm to search for identical and similar compounds in the mass spectra database system MassLib.⁵⁴⁵ The aim is to optimise spectral similarity to obtain “hit-lists” containing relevant chemical structure information. The end result would then be unknown substance prediction based on the comparison of the probabilities of substance classes in the database;⁵⁴⁶

⁵³⁸ McLafferty FW *et al.* “Probability based matching of mass spectra. Rapid identification of specific compounds in mixtures” 1974 *Org Mass Spec* 9:690–702.

⁵³⁹ Stein SE “Estimating probabilities of correct identification from results of mass spectral library searches” 1994 *J Am Soc Mass Spectrom* 5: 316–323.

⁵⁴⁰ Stein SE and Scott DR “Optimization and testing of mass spectral library search algorithms for compound identification” 1994 *J Am Soc Mass Spec* 5:859–866.

⁵⁴¹ Wei X *et al.* “Compound identification in GC-MS by simultaneously evaluating mass spectrum and retention index” 2014 *Analyst* 139:2507–2514.

⁵⁴² Wallace WE *et al.* “Mass Spectral Library Quality Assurance by Inter-Library Comparison” 2017 *J Am Soc Mass Spec* 28:733–738.

⁵⁴³ Demuth W *et al.* “Spectral similarity versus structural similarity: mass spectrometry” 2004 *Analytica Chimica Acta* 516(1-2):75-85.

⁵⁴⁴ Kwok KS *et al.* “Computer-aided interpretation of mass spectra. III. Self-training interpretive and retrieval system” 1973 *J Am Soc Mass Spec* 95:4185-4194.

⁵⁴⁵ MassLib “Mass spectral database system” MSP Kofel <https://www.msp.ch/mass-spectrometry/masslib> (Date of use: 3 January 2020).

⁵⁴⁶ Henneburg D *et al.* “Computer Aided Interpretation of Mass Spectra” 1993 *Org Mass Spec* 28:198-206.

(3) Retrieved spectra are weighted according to similarity to the spectra of the unknown compound. It also includes a “peaks-in-common” screening step to reduce search times, as well as an optimised dot product function to provide the match factor.⁵⁴⁷

The majority of the above mentioned studies focused on the recognition of single substructures and did not consider the overall similarity of chemical structures.

Recent research from Stephen Stein at the National Institute of Standards and Technology (NIST) provides some direction on illicit drug identification when standard spectra are not available, by using combined fragment-ion and neutral-loss matching algorithms.⁵⁴⁸ Davison *et al.*⁵⁴⁹ also considered recommended acceptance criteria for the analysis of seized drugs using GC-MS, hence providing a more sound approach to an acceptance criteria. They recommended that search algorithms that assume fragment ions are independent variables that should be re-evaluated to test the effect of correlated ion abundances.

All of these recommendations were studied and will be encapsulated in an ASTM standard that is currently in the OSAC approval process⁵⁵⁰ (this is addressed in more detail in paragraph 5.6.2 of this chapter).

5.3.6 Other recommendations from SWGFAST

Another leader on recommended standards is the SWGFAST working group. This working group developed minimum standards on the following:

- A Code of Professional Practice for Drug Analysts

⁵⁴⁷ Stein SE “Chemical Substructure Identification by Mass Spectral Library Searching” 1995 *J Am Soc Mass Spec* 6:644-655.

⁵⁴⁸ Stein SE *et al.* “Combining fragment-ion and neutral-loss matching during Mass Spectral library searching: A new general purpose algorithm applicable to illicit drug identification” 2017 *Anal Chem* 89:13261-13268.

⁵⁴⁹ Davidson TJ *et al.* “Comparison of measured and recommended acceptance criteria for the analysis of seized drugs using Gas Chromatography–Mass Spectrometry (GC–MS)” 2018 *Forensic Chem* 10:15-26.

⁵⁵⁰ ASTM WK65067 Practice for Assessment of Gas Chromatography and Electron Ionization Mass Spectrometry Data during the Qualitative Analysis of Seized Drugs 2019.

- Education and Training
- Methods of Analysis/Sampling of Seized Drugs for Qualitative Analysis
- Methods of Analysis/Drug Identification
- Methods of Analysis/Clandestine Laboratory Evidence
- Methods of Analysis/Analogue and Structural Class Determinations
- Quality Assurance/General Practices
- Quality Assurance/Validation of Analytical Methods
- Quality Assurance/Uncertainty⁵⁵¹

Since 1997, the SWGDRUG continued with updates following advances in technology, changes in accreditation requirements, and new legislative requirements. The working group consists of contributing members from around the globe. They also rely on the input from the larger forensic science community. The primary mission of the working group is to continue the development of minimum standards that can be used by international drug laboratories and criminal justice systems when admitting drug evidence in courts. This was not always possible as different jurisdictions had their own requirements for their respective drug laboratories. One such an example is when the Forensic Science Laboratory in South Africa adopted the sampling scheme as recommended by SWGDRUG in 2003. Prior to this date, crime laboratories in South Africa used non-statistical methods in the quest to determine the appropriate sample size.⁵⁵² These methods, however, did not allow for the use of pre-established standard and statistical probabilities. The hypergeometric distribution and Bayesian method both provided such standards in the form of confidence levels. Accordingly, these methods permit strong probability statements to be made regarding the portion of the exhibit that contains a controlled substance.⁵⁵³ Over a short period, the Controlled Substances Unit experienced an increased turnaround time on forensic reports and the National Prosecuting Authority (NPA) needed answers on the ever increasing report submissions.

⁵⁵¹ SWGDRUG *Recommendations* Version 8 2019.

⁵⁵² United Nations International Drug Control Program (UNDCP) *STR/NAR/06-11 Recommended methods for testing* 1986.

⁵⁵³ Tzidony D and Ravreby M "A statistical approach to drug sampling: a case study" 1992 *J Forensic Sci* 37(6):1541-1549. Also, Colón M *et al.* "Representative sampling of 'street' drug exhibits" 1993 *J Forensic Sci* 37(3):641-648. Also, Coulson SA *et al.* "How many samples from a drug seizure need to be analyzed" 2001 *J Forensic Sci* 46(6):1456-1461.

The statistical methods satisfied the quality requirements, but not the criminal justice system, as many cases were withdrawn due to lapsed time for court hearings. After several meetings between management of the laboratory and representatives from the NPA, it was recommended that only one sample needed to be analysed by the laboratory for possession cases. The state only had to prove that a person was in possession of a controlled substance and that the quantity of samples was not relevant for prosecution. However, in dealing with these cases the state had to prove both intent with regard to selling the illicit drug and that all samples contained a controlled substance. It was further required that the reports clearly state that only one sample was analysed in possession cases, not to mislead the courts. The change not only satisfied both the legal system requirements and the quality management system requirements. It also reduced the turnaround times for reports in South Africa by months.

In the latest revision of SWGDRUG recommendations,⁵⁵⁴ it is stated that the sampling strategy should be based on jurisdictional requirements and both a non-statistical and statistical approach can be followed, as long as it is well documented in the forensic report.

5.4 First challenges where the law exposed the scientific method

Early legal challenges in the context of controlled substance regulation revolved around linguistic issues relevant to the interpretation of the legal provisions. Although forensic chemists would analyse the unknown substances (liquids, powders, tablets, or plant materials), they would be challenged on chemical compositions or physical appearance of those substances. The first example that illustrates this challenge arose in 1965 in the case of *Leary v. United States*.⁵⁵⁵ Dr. Timothy Leary, was arrested for violation of two federal statutes governing traffic in marihuana⁵⁵⁶ (cannabis), or botanically known as *Cannabis Sativa Linne*.⁵⁵⁷

⁵⁵⁴ SWGDRUG *Recommendations* Version 8 June 2019.

⁵⁵⁵ *Leary v. United States* 395 U.S. 6, 1965.

⁵⁵⁶ Marihuana, a term of Mexican origin, is the dried leaves and flowering tops of a plant species commonly known as hemp.

⁵⁵⁷ Pollio A "The Name of Cannabis: A Short Guide for Non-botanists" 2016 *Cannabis Cannabinoid Res* 1(1):234–238.

This case marked the start of the plant species debate on physical recognition of the plant *Cannabis Sativa Linne*, followed by two other similar cases, namely those of *United States v. John Moore*⁵⁵⁸ and *United States v. Wuco*.⁵⁵⁹ It was originally believed that different variations of the Cannabis plant existed in Mexico and India. The name *Cannabis Indica* was given to Cannabis *Sativa Linne* grown in India.⁵⁶⁰ It was established in *Leary v. United States* that there is only one species of the plant, Cannabis *Sativa Linne*.⁵⁶¹ The difference in physical appearances was contributed to different soil content and climate conditions where the plant is grown in different locations. For example, Mexican marihuana was determined to contain a higher level of the psychoactive substance THC and preferred by end users.⁵⁶² In the case of *Leary*, the court found no validity in the appeal and concluded the state met its burden of proof that the substances transferred was indeed Cannabis *Sativa Linne*.⁵⁶³ It was later proved by the state, in *United States v. Wuco*, that microscopic analysis of the plant variations was similar in appearance and that all the variants in fact belong to the Taxonomy “*Cannabis Sativa Linne*”, with the active psychoactive substance Delta-9-Tetrahydrocannabinol (THC). After these cases, the debate regarding the cannabis variations disappeared and dealers searched for other ways to circumvent the regulation of cannabis.

There is little to none literature concerning legal challenges relating to the instrumentation used in controlled substance identification during the 20th century. The first case on record for results obtained from a GC-MS was in 1977, where data from the mass spectrometer was admitted as evidence in a case involving the detection of a pesticide known as Tetrachlorodibenzodioxin (TCDD) in animal tissues from the Siuslaw National Forest.⁵⁶⁴

⁵⁵⁸ *United States v. John Moore* 1971, 446 F.2d 448.

⁵⁵⁹ *United States v. Wuco*, 1976, 535 F. 2d 1200.

⁵⁶⁰ Pollio A The Name of Cannabis 2016.

⁵⁶¹ *Leary v. United States*, 395 U.S. 6, 50, 89 S.Ct. 1532, 23 L.Ed.2d 57 (1969).

⁵⁶² *Leary v. United States*, at 49, 89 S.Ct. 1532.

⁵⁶³ The fact that 7 of the Act of March 3, 1915, 38 Stat. 820, Title 21 (Food and Drugs), U.S.C. 209, proclaiming it to be unlawful for any person or firm whose permanent allegiance is due the United States to sell or deliver to any other person the substances listed therein, including Cannabis indica, does not detract from this conclusion. That section, as pointed out by the District Court, was intended to prohibit the transfer of that substance in the United States consular districts in China.

⁵⁶⁴ *Citizens against Toxic Sprays, Inc. et al., Plaintiffs, v. Bob Bergland, Secretary, United States Department of Agriculture et. al., Defendant Inventor.* United States district court for the district of Oregon. 428 F. Suppl. 908; 1977 U.S. District LEXIS 17049; 9 ERC (BNA) 1897; 7 ELR 20325.

In 1978, a judge ruled to allow the test results of GC-MS as evidence in a capital murder trial of Dr Mario Jascalevich, who was believed to have killed 25 of his patients between 1965 and 1966 using Curare, a poisonous substance, in very low quantities. At the time, however, no instruments or techniques could detect the poison and Dr. Jascalevich was acquitted in 1967.

In 1975, the New York Times received a tip-off that the events involving Dr Jascalevich might be worth re-examination and the reporter, Myron Farber, began investigating the case. He interviewed relatives of the deceased and hospital staff. He obtained case notes and other original files and published three long articles on his findings in the New York Times. Dr. Michael Baden, Deputy Medical Examiner for New York, who reviewed the case-notes, commented as follows:

“It is my professional opinion that the majority of the cases reviewed are not explainable on the basis of natural causes and are consistent with having been caused by a respiratory depressant. It is my opinion that recent technological advances now permit the detection of very minute amounts of curare removed from dead bodies”.⁵⁶⁵

Relatives of five of the alleged patient-victims agreed to exhumations. Tissue samples were taken and divided among toxicology laboratories. Curare was found in several of the bodies and Jascalevich was arraigned for the murder of these patients. The 34-week trial, conducted before 18 jurors, started on 28 February 1978.⁵⁶⁶ The scientific method was accepted and jurors agreed on the guilt of Jascalevich.

In two other criminal cases,⁵⁶⁷ the defence argued that the state failed to establish a proper foundation for the admission of GC-MS results and expert opinion. The emphasis was placed on the expertise of the chemist’s testimony on the use of GC-MS in the analysis of controlled substances. In both cases, the courts found the experts knowledgeable and experienced to testify as experts. The courts also found that GC-MS was an accepted and valid scientific method in the

⁵⁶⁵ Hall LH and Hirsch RF “Detection of curare in the Jascalevich murder trial” 1979 *Anal Chem* 51(8):812A-819A.

⁵⁶⁶ Bird D “Detection of Curare in Jascalevich murder trial” 1978-06-23 *New York Times*.

⁵⁶⁷ *Markley vs State*, 603 N.E 2d 891 (Ind. Ct. App. 1992) and *Lopez vs State*, 2005 WL1405770 (Tex. App. June 16, 2005).

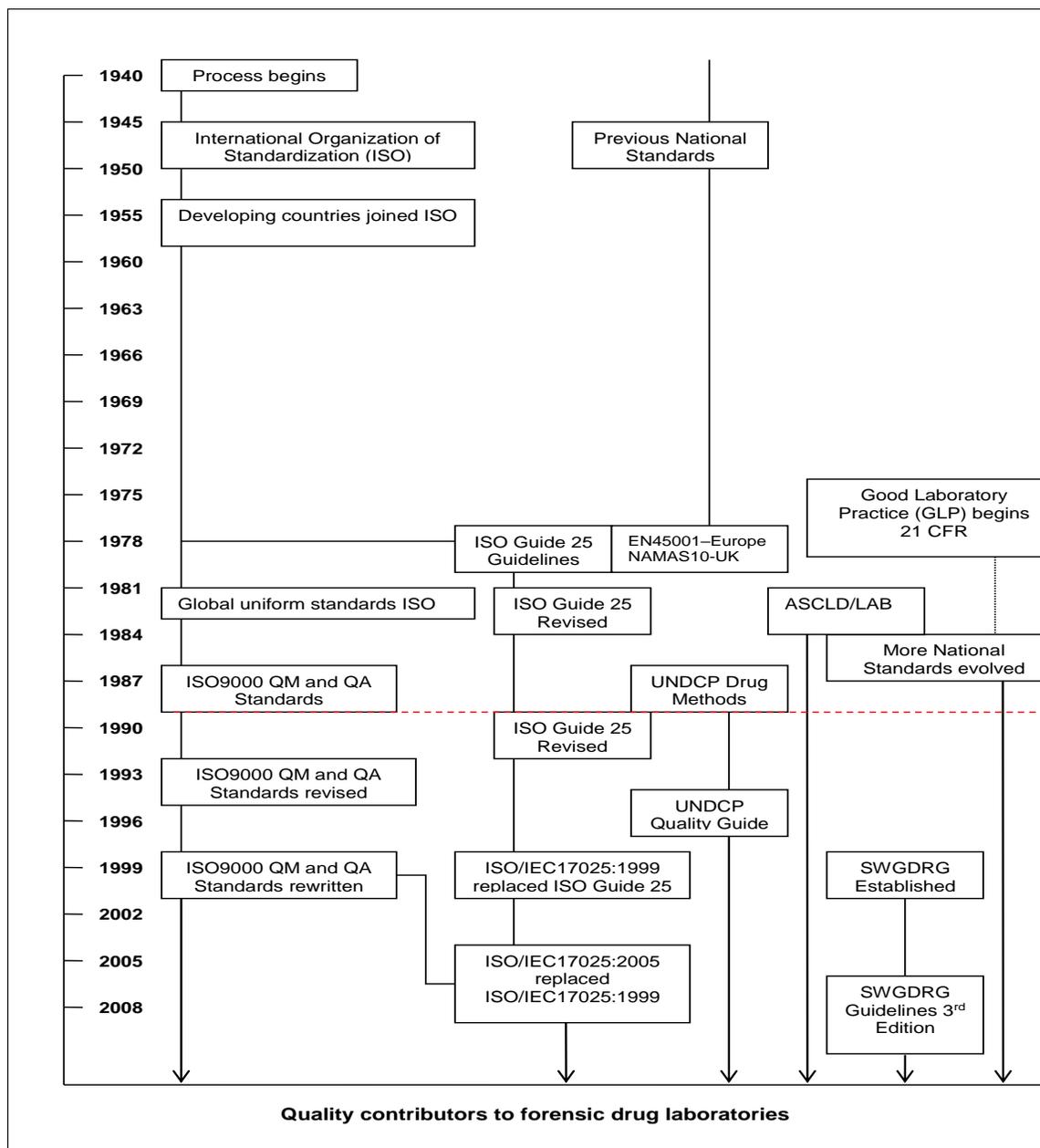
science community for identifying the chemical composition of controlled substances, and expert witnesses in both cases presented the scientific principles underpinning the method.

5.5 Dynamic changes in drugs of abuse

The major dynamic changes in forensic drug analysis globally may be attributed to legislation (discussed in section 5.2); scientific developments (discussed in section 5.3), and quality systems. With regard to the latter, a quality timeline for the period 1940 to 2008 pertaining to forensic drug laboratories, derived and summarised from a 2010 study by Venter,⁵⁶⁸ is provided in Figure 5.3 below.

⁵⁶⁸ Venter *Quality* 2010.

Figure 5.3 Flowchart showing the quality timeline in forensic drug laboratories⁵⁶⁹



⁵⁶⁹ Venter "Quality" 2010.

Since 2008, ISO17025:2017 replaced the 2005 document; United Nations Office on Drugs and Crime (UNODC) continued adding new publications to include designer drugs;⁵⁷⁰ SWGDRUG moved to version 8 on recommendations;⁵⁷¹ and the American Society of Crime Laboratory Directors/Laboratory Accreditation Board (ASCLD/LAB) moved from a legacy accreditation program to an international program (adopting ISO17025 as part of their accreditation requirements). Moreover, the ANSI-ASQ National Accreditation Board (ANAB) recently signed an affiliation agreement with ASCLD/LAB, merging ASCLD/LAB into ANAB.⁵⁷²

5.5.1 Value of quality standards and professional ethical conduct

The use of well-defined quality standards is essential to the drug analysis workplace and ensure credibility to analytical results. The evidence submitted to forensic laboratories should be analysed accurately and precisely, followed by objective reporting based on the results obtained.

The ultimate judge of the quality of work in a forensic drug laboratory ought to be the court of law, where these results may be contested by the defence. Judges and/or juries within criminal justice systems rely on the professional integrity of drug chemists that work in forensic science laboratories, as well as the management of these laboratories to ensure that the highest standards are followed and maintained. Drug chemists working should use best international practices in both techniques and equipment. Techniques used should generally be accepted within the appropriate scientific community; should have been peer reviewed, and the theory upon which the technique is based should have been tested or should be testable or replicable. Lastly, but most importantly, standards should exist for controlling the application of the technique used. Incorrect test results presented to court could severely damage the credibility of the laboratory; lead to injustice, and break trust with the public. For forensic drug laboratories to assure and maintain quality, a system

⁵⁷⁰ UNODC Recommended methods for the identification and analysis seized materials 2019.
<https://www.unodc.org/unodc/en/scientists/publications-drug-testing-laboratories.html> (Date of use: 19 May 2019).

⁵⁷¹ SWGDRUG *Recommendations* 2019.

⁵⁷² ANSI National Accreditation Board (ANAB) "ANAB and ASCLD/LAB Merge Forensics Operations"
<https://www.anab.org/latest-news/anab-and-asclclab-merge-operations> (Date of use: 19 May 2019).

should be established wherein its commitment to good laboratory practices and laboratory specific standards are documented, subsequently implemented and periodically monitored.

A quality system should be designed to guarantee that all the test procedures falls within established performance criteria, where the validity of the analytical data is maintained and that preventative steps and corrective action protocols are in place for anticipated problems. When forensic drug laboratories function under a well-defined quality system, additional skills sets will develop by the chemists, performing analytical work. These skill sets include continuous improvement of managerial and technical skills; self-discipline; analytical thinking, and problem solving. With a well-defined quality system, all processes and activities in the laboratory are managed in a controlled manner, which in turn would constantly improve the effectiveness and efficiency of the laboratory's performance.

When management lacks quality control and self-assessment, problems will surface that will place all crime laboratories under severe scrutiny. It is not just the scientific method that can undermine the unequivocal answer for the criminal justice system, but those performing the analytical task can equally damage the relationship between forensic science and the criminal justice system. A number of incidents in crime laboratories exemplified causes of misconduct by chemists working in crime laboratories, placing all other crime laboratories under serious scrutiny and suspicion. Table 5.6 below lists a number of malpractice incidents that took place in forensic crime laboratories. "Dry-labbing" in forensic science is when a scientist reports a fictional, yet plausible analytical result in lieu of performing the analytical test (falsifying experimental results).

Table 5.6 Malpractices reported globally

Scientist	State/Country	Misconduct	Number of cases impacted
Annie Dookhan ⁵⁷³	Massachusetts, USA	Falsifying evidence used in criminal cases (2003-2012)	21,587 cases dismissed ⁵⁷⁴
Sonja Farak ⁵⁷⁵	Massachusetts, USA	Stole drugs to support addiction (2003-2012)	11,000 cases dismissed
Jonathan Salvador ⁵⁷⁶	Texas, USA	Using evidence in one case and report the results in another case (2006-2012)	4,944 cases re-analysed ⁵⁷⁷
Nika Larsen ⁵⁷⁸	Oregon, USA	Stole drugs to support addiction (2013-2015)	Reviewed more than 2,500 cases
Kamakant Shah ⁵⁷⁹	New Jersey, USA	“Dry-labbing” fake drug analysis (2005-2015)	1,300 cases re-tested
Derek Thrush ⁵⁸⁰	Montana, USA	Stole drugs to support addiction (2018)	25 cases vacated
Ana Romero ⁵⁸¹	Texas, USA	“Dry-labbing” blood alcohol samples (2006-2015)	22 wrong convictions

⁵⁷³ Ballou B and Estes A “Chemist Admitted Wrongdoing in Lab Scandal” 2012-09-26 *Boston Globe*.

⁵⁷⁴ *Kevin Bridgeman v. District attorney for the Suffolk District*, Declaratory Judgement, Supreme Judicial Court for Suffolk County, No. SJ-2014-0005, Commonwealth of Massachusetts, 19 April 2017.

⁵⁷⁵ Solotaroff P “And Justice for None: Inside Biggest Law Enforcement Scandal in Massachusetts History” 2018-01-03 *ROLLING STONE*.

⁵⁷⁶ DePrang E “Fake Lab Results Endanger Thousands of Drug Convictions” 2013-07-08 *Texas Observer*.

⁵⁷⁷ Report of the Texas Forensic Science Commission Texas Department of Public Safety Houston Regional Crime Laboratory Self-Disclosure 5 April 2013.

⁵⁷⁸ Bernstein M “Former state police forensic scientist sentenced to 3 years in federal prison” 2016-12-12 *The Oregonian*.

⁵⁷⁹ Sullivan SP “More than a thousand drug cases will be tossed after N.J. State Police lab scandal” 2018-05-10 *True Jersey*. Also Guion P “New Jersey State Police employee may have faked thousands of drug test results” 2016-03-03 *Independent*.

⁵⁸⁰ Christian P “Montana State Crime lab chemist charged with stealing meth” 2018-02-23 *Newstalk KGVO*.

⁵⁸¹ Martinez A “Defense lawyers allege ex-DPS forensic analyst had history of falsifying drug, blood tests” 2018-06-13 *El Paso Times*.

Randex Testing Services ⁵⁸²	Manchester, UK	Data manipulation (2017)	10,000 cases re-analysed
Motherisk drug testing lab. ⁵⁸³	Toronto, Canada	Hair testing for drug and alcohol use in child protection cases unreliable (2005-2015)	24,000 hair samples, from 16,000 people

Table 5.6 also details the significant impact of the unethical behavior of these scientists. These acts elicited severe criticism from various corners in the criminal justice system. Sarah Chu, senior forensic advocate at the Innocence Project, stated that some defendants pleaded guilty in instances where they might have been found innocent with indisputable scientific evidence.⁵⁸⁴ The Innocence Project recommended independent investigations on malpractice cases in these laboratories.⁵⁸⁵ Chu also recommended root cause analyses of the issues that led to these problems and advocated for better policies that will prohibit unethical behavior in crime laboratories. The executive director of the America Society of Crime Laboratory Directors (ASCLD), Jean Stover, admitted that some crime laboratories have “bad apples” and scientists do make mistakes, unintentionally or intentionally.⁵⁸⁶ The frequent exposure of these scientists is an indication that systems do pick up on the problems within the crime laboratories. Stover observed that the system is improving and will become more transparent.

Josh Lee, a United States criminal defence attorney at Ward, Lee and Coats, believes that the problem is much larger than just a few rogue chemists. He suggests that those caught producing questionable work or fabricating results should be exposed in order to flag those malpractice laboratories. Another criminal defence attorney, Justin McShane, attributes the problems to a

⁵⁸² Dearden L “Convictions in doubt as more than 10,000 cases could be affected by data manipulation at forensics lab” 2017-11-21 *Independent*.

⁵⁸³ Mendleson R “Separated by hair” 2017-10-19 *Toronto Star*.

⁵⁸⁴ Trager R “Hard questions after litany of forensic failures at US labs” 2014-12-01 *Chemistry World*.

⁵⁸⁵ The Innocence Project News “*Investigating Forensic Problems in the United States: Executive Summary*” 2009-10-03. <https://www.innocenceproject.org/investigating-forensic-problems-in-the-united-states-executive-summary/> (Date of use: 12 January 2020).

⁵⁸⁶ Trager *Hard questions* 2014.

systematic failure of the quality management and assurance systems, which should be addressed in those areas.⁵⁸⁷

In some of the cases referred to in Table 5.6, the lack of effective supervision was highlighted as aggravating the misconduct. Supervisors should be better skilled to be pro-active when red flags, such as changes in the conduct of exceptional or over-performers are observed. Dookhan, mentioned in table 5.6 above, for example processed many more samples than the average analyst in the laboratory and that alone should have raised questions by the supervisor on her methodology followed in achieving this high performance. When scientists are promoted to supervisory positions, they often lack managerial skills, such as awareness and system assessment, which opens the window for unethical employees to get away with misconduct for extended periods of time.

In 2010, the American Chemical Society (ACS) recommended new quality control frameworks to strengthen and supplement existing requirements for accreditation, and also more frequent inspections and enforcement.⁵⁸⁸ The ACS also advocated improvement in scientific rigour and continued to quantitatively assess and improve the accuracy of analytical methods. One of their statements calls for rigorous accreditation, certification of all scientists and practitioners, and the establishment and promotion of ethical standards, with the belief that it would limit malpractices in crime laboratories.

Involvement from external or third parties is not new to forensic science and should not always be viewed in a negative light. The next section will discuss some of the external bodies or third parties providing input on issues relating to forensic drug chemistry.

⁵⁸⁷ Trager *Hard questions* 2014.

⁵⁸⁸ American Chemical Society (ACS) “*Forensic Science*” Position statement 2010.

<https://www.acs.org/content/acs/en/policy/publicpolicies/science-policy/forensic-science.html>

(Date of use: 23 May 2019).

5.6 External entities that influenced the credibility of drug chemistry

5.6.1 The NAS Report

The first in a series of events that had an impact on the credibility of drug chemistry arose when the National Research Council of the United States National Academy of Science (NAS) published a report titled, “Strengthen Forensic Science in the United States: A Path Forward”.⁵⁸⁹ This report iterated the need for greater scientific rigour in the Forensic Science Profession, amongst a total of thirteen recommendations contained in the report. Scant attention was given to forensic drug chemistry, as certain disciplines required more attention than others. These will be discussed elsewhere in this thesis.

All the efforts on research and the work of the SWGDRUG was commended by the NAS working committee, when they referred to the analysis of controlled substances as “a mature forensic science discipline and one of the areas with a strong scientific underpinning” and that “the analytical methods used have been adopted from classical analytical chemistry, and there is broad agreement nationwide about best practices”.⁵⁹⁰ Even though the standard practices were only recommendations, the SWGDRUG’s standards were widely adopted by drug analysis laboratories in the United States and elsewhere. These recommendations are recognised to represent the minimum standards that may be modified to address unique jurisdictional requirements.

The NAS report acknowledged the analytical methodology used in crime drug laboratories, which included presumptive field testing and the use of GC-MS. They also described it as a near universal test for identifying unknown substances.⁵⁹¹ Although SWGDRUG recommended both statistical and non-statistical models in sampling, a number of the crime laboratories continued to use old non-statistical methods as long as these met their jurisdictional requirements for possession or dealing in controlled substances.⁵⁹² As mentioned in paragraph 5.3.6, forensic science laboratories

⁵⁸⁹ Committee on Identifying the Needs of the Forensic Sciences Community, National Research Council. “*Strengthening forensic science in the United States: a path forward*” Washington DC: National Academy of Sciences 2009.

⁵⁹⁰ NAS Report *Strengthening Forensic Science* 2009 [135].

⁵⁹¹ NAS Report *Strengthening Forensic Science* 2009 [135].

⁵⁹² SWGDRUG *Recommendations* 2019 [7].

complied with jurisdictional requirements and the relevant changes that are called for, would need to be come from the law makers, before crime laboratories can make any changes.

Another problem highlighted by the NAS report was the absence of information in forensic drug reports.⁵⁹³ In most laboratory reports, the sampling method and analytical method applied were not included. It may not provide enough detail to enable a peer or other courtroom participant to understand, and, if needed, question the sampling scheme, process(es) of analysis, or interpretation.

The SWGDRUG forthwith addressed the problems indicated by the NAS report; one of which was the supplemental addition of examples on report writing published in 2011 and revised in 2016. The newest revised document⁵⁹⁴ of recommendations stipulates the following with regard to reporting under sections IIIA, IIID and IVA:

- IIIA. Statistically selected sample(s)
 - o The language in the report must make it clear to the reader that the results are based on a sampling plan.
- IIIA. Non-Statistically selected sample(s)
 - o The language in the report must make it clear to the reader that the results apply to only the tested units.
- IIID. Structural Class Determinations – Reporting
 - o All conclusions and opinions expressed in written or oral form shall be based on sufficient supporting evidence, data, or information, as defined by laboratory procedures.
 - o Conclusions and opinions reported shall be accurate, clear, and meet the jurisdictional requirements. The report must also include any relevant assumptions or limitations (e.g. potentially exculpatory information), to allow the court to make the final decision.

⁵⁹³ NAS Report Strengthening Forensic Science 2009 [135].

⁵⁹⁴ SWGDRUG *Recommendations* 2019 [7].

- o The report should clearly indicate what elements of the legal requirements were evaluated and what elements were not evaluated.
- o The scope of opinions and conclusions reported, in either written or oral form, shall not go beyond the knowledge, training, and experience of the analyst.
- IVA. Report writing
 - o These reports shall include the following information:
 - title of report
 - identity and location of the testing laboratory
 - unique case identifier (on each page) clear identification of the end of the report (e.g., Page 3 of 3)
 - submitting agency
 - date of receipt of evidence
 - date of report
 - descriptive list of submitted evidence
 - identity and signature (or electronic equivalent) of analyst
 - results / conclusions
 - a list of analytical techniques employed
 - sampling (see Part III A - Reporting)
 - uncertainty (see Part IV C - Uncertainty).

If elements listed above are not included in the report, the laboratory shall have documented reasons (i.e. specific accreditation, customer or jurisdictional considerations), for not doing so.⁵⁹⁵

5.6.2 Establishment of the Seized Drugs OSAC sub-committee

On February 4, 2014, the National Institute of Standards and Technology (NIST) announced the formation of the Organization of Scientific Area Committees (OSAC). The OSAC scientific area committees (SACs) provide direction and coordination for the work performed by the OSAC discipline-specific subcommittees. One of these subcommittees is the Seized Drug committee

⁵⁹⁵ SWGDRUG *Recommendations* 2019 [42].

which inherited all previous documentation of SWGDRUG in their task to establish the American Society for Testing and Materials (ASTM) standards. They channeled the new work and activities through the SACs to the Forensic Science Standards Board, and interfaced with resource committees on human factors, legal, and, quality issues. Although the issue of human factor resource is a new addition to the context of controlled substances, it has already become a familiar term in the fingerprint community since 2012 and will be discussed in the chapter relating to fingerprint evidence in this dissertation.

The role of the OSAC was to strengthen the United States' use of forensic science by supporting the development and promulgation of forensic science consensus documentary standards and guidelines, determining each forensic discipline's research and measurement standard needs, and ensuring that a sufficient scientific basis exists for each discipline.⁵⁹⁶ The sub-committee evaluates all standards in place (also those established through SWGDRUG). The sub-committee also revisited existing ASTM seized drug related standards registered, and has updated and published these as new improved standards on record.⁵⁹⁷ Although ASTM standards are voluntary standards, government regulators often give voluntary standards the force of law by citing them in laws, regulations and codes.

The OSAC Seized Drug sub-committee may only consist of members of the United States, but other interested persons may provide comments or recommendations on the standards during the ASTM standard approval phase. Because many role players from the larger science community now review all standards, the standard approvals process has become a lengthy one. Since 2014, only two ASTM standards were approved,⁵⁹⁸ three are under public review,⁵⁹⁹ and three are

⁵⁹⁶ NIST "What is OSAC and what we do" 2019. <https://www.nist.gov/topics/organization-scientific-area-committees-forensic-science> (Date of use: 12 January 2020).

⁵⁹⁷ NIST "OSAC Standards Approval Process" 2020. <https://www.nist.gov/topics/organization-scientific-area-committees-forensic-science/standards-approval-process> (Date of use: 12 January 2020).

⁵⁹⁸ ASTM E2329-17: Standard Practice for the Identification of Seized Drugs and ASTM E2548-11e1: Standard Guide for Sampling Seized Drugs for Qualitative and Quantitative Analysis.

⁵⁹⁹ ASTM E2764 Standard Practice for Uncertainty Assessment in the Context of Seized-Drug Analysis; ASTM E2882 Standard Guide for Analysis of Clandestine Drug Laboratory Evidence; ASTM WK65067 Practice for Assessment of Gas Chromatography and Electron Ionization Mass Spectrometry Data during the Qualitative Analysis of Seized Drugs.

works-in-progress.⁶⁰⁰ Despite of all the efforts made within this specific science community, the value of these standards will be no different than previously developed standards, unless accreditation bodies or jurisdictions decide to make these mandatory for compliance within crime laboratories or any other testing laboratory producing results for legal purposes.

5.6.3 The PCAST Report

The President's Council of Advisors on Science and Technology (PCAST) released a report on the status of Forensic Science in September 2016. This report did not make any specific mention of seized drug analysis. The report mostly focused on the validity of feature-comparison methods in forensic science. It does not, however, mean that there are no problems within forensic drug analysis. It simply means other disciplines are more in need of reform than forensic drug chemistry. The fate of the PCAST report will be discussed in this thesis in those chapters addressing the disciplines most scrutinised by the Council. The OSAC Subcommittee on Seized Drugs did acknowledge the report and as a result, in a pro-active way, started with the development of standards that would address interpretation of data generated by scientific instrumentation (mass spectra and FTIR spectra).

5.7 Future developments within forensic drug chemistry

There is no doubt that the scientific validity will continue to be challenged in judicial proceedings. It will be important for the forensic drug community to acknowledge past challenges and failures, and be more pro-active in addressing potential threats and shortcomings in the future. The following key aspects should be assessed based on past experiences:

- (1) With regard to the continued increase in the development of new designer drugs, legislation should be written in such a manner that it anticipates and includes any potential dangerous dependent forming substance and any of its analogs before it surfaces on the illicit market (similar to Pharmacophore schedules);

⁶⁰⁰ Standard Guide for Intralaboratory Blind Quality Control Program for Seized Drugs Analysis Standard Guide for the Development and Suitability Assessment of Electron Ionization-Mass Spectral (EI-MS) Libraries for Databases for Forensic Identification; and Standard Guide for Assessment of Infrared Spectroscopy Data During the Qualitative Analysis of Seized Drugs.

- (2) Designing of analytical equipment/instrumentation that is more affordable, faster and durable, but continue to comply with scientific validity;
- (3) Interpretation models of mass spectra other than just a comparison based on similarity;
- (4) Legal professionals should have a better understanding of scientific limitations and analytical models used by scientists;
- (5) Introduction of dedicated drug courts should be considered;
- (6) National, state, or regional forensic commissions should be constituted within reach of any judicial system where suspicious results in crime reports are detected;
- (7) Effective supervision courses should be developed and form part of certification processes within crime laboratories;
- (8) Preventative assessment of the role of human factors in analytical schemes should be explored in order to be more attuned to employee behavior, including unethical conduct.

5.7.1 Continued increase in the development of new designer drugs and pharmacophore regulation

It is clear from the 16th, 17th, and 18th Interpol International Forensic Science Managers Symposia held in France on October 2010, October 2013, and October 2016 respectively, which designer drugs increased threefold since the beginning of the 21st century. Every jurisdiction and crime laboratory has been and will continue to be challenged with these ever increasing harmful substances for human consumption. The ingenuity of clandestine chemists will continue until legislation is written in such way that criminal sanctions will apply to any person producing a substance knowing that it will alter or act as a drug that is harmful for human consumption, unless it is properly researched through clinical trials and approved by health regulating authorities such as the FDA.

The first step in such a direction has been taken by lawmakers in the State of Ohio in the United States. Chapter 4729-11 of the Controlled Substances Schedules included the term "Pharmacophore" which includes the portion of a chemical structure that confers the activity of the

substance.⁶⁰¹ Dr. Jon Sprague, who is the director of the Ohio Attorney General's Center for the Future of Forensic Science at the Bowling Green State University, is a pharmacologist and researches the prospect to enact a Federal Pharmacophore Act that will ultimately prohibit the synthesis of designer drugs.⁶⁰² He also advocates that such substances have to be tested for differences in both pharmacological and toxicological effects to ensure safety before approval. He also states that such legislation will provide context to the issue and guidance to questions such as the determination of structural similarity based on commonality of individual subgroups between scheduled and unscheduled drugs of abuse. In 2018, he published a paper to illustrate the influence of functional group modification of synthetic cathinones on drug pharmacokinetics.⁶⁰³ Forensic drug chemists should not be concerned about pharmacokinetics, as their role will only be to identify a chemical structure of the unknown substance. If a base structure can be derived from the chemical structure, it will be falling within the pharmacophore regulated schedules.

5.7.2 Instrumental design and financial costs

Most forensic crime laboratories are faced with budget declines and newly designed instrumentation that are more specific in structure determination come with a large price tag. Smaller crime laboratories are unlikely to spend hundreds of thousands of dollars on expensive equipment to analyse samples from a small quantity of cases.

Vendors should continue to find ways to design less expensive instruments that are fast in analytical procedures with a high scientific validity. Policies and procedures should be in place at the laboratory to allow for samples to be outsourced or transferred to better equipped laboratories for identification purposes, if they do not possess fit-for-purpose instrumentation for non-standard

⁶⁰¹ *The Pharmacophore Rule* (Ohio Administrative Code 4729-11-02) in 2014.
<http://codes.ohio.gov/oac/4729-11> (Date of use: 15 January 2020).

“A pharmacophore represents the minimum required parts of a drug or molecule needed to bind to a receptor. Binding to a receptor generates an effect in the body (usually in the brain), which has been documented by scientific studies. Ohio Administrative Code 4729-11-02 gives an established forensic laboratory the ability to identify the synthetic cannabinoid pharmacophore found within a larger drug molecule.

⁶⁰² Carle J “The chemistry of clandestine drugs” January 2016 *Bowling Green State University News*.

⁶⁰³ Calinski DM et al. A review of the influence of functional group modifications to the core scaffold of synthetic cathinones on drug pharmacokinetics (Psychopharmacology Springer-Verlag GmbH Germany part of Springer Nature 2018).

methods. This will allow smaller or satellite laboratories to focus on routine type cases and centralised laboratories will deal with more challenging samples.

There is a fine balance between the issues of the price in combatting crime and whether the cost per sample analysis should exceed the value of the punishment. For example, if the cost per sample analysis is \$200 using a GC-MS/MS and the punishment for a first-time possessor of a substance is a verbal warning, the question rightly arises whether it worth the analysis.⁶⁰⁴ Could a preliminary identification of the substance serve as enough evidence to justify a verbal warning when the price per sample analysis continues to increase and the results or success on convictions do not balance out? If so, could it be said that the public-at-large would not see justice to be served? Longer sentences for drug dealers arguably do not benefit the general public. The number of imprisoned drug offenders in the United States has risen from 24,363 in 1980 to 207,339 in 2015, at a 595% cost increase for federal inmates.⁶⁰⁵ Recently, President Trump's administration advocated the death penalty for drug dealers.⁶⁰⁶ If or when such a law comes in effect, the scientific validity of analytical schemes in drug analysis will be placed under the legal magnifying glass and may be challenged to its fullest extent, similar to what occurred with regard to DNA, fingerprint, and firearm analysis.

5.7.3 Legal professionals should understand scientific validity

There is no need for legal professionals working within criminal law to be scientists, but a number of issues can be solved before hearings if all parties involved have some knowledge of the scientific method and the limitations thereof. For many years, forensic drug scientists had to testify to “a high degree of scientific certainty” in the United States, a statement that is never used in the scientific community. Similar to the contexts of DNA and fingerprints, the statement does not indicate an

⁶⁰⁴ Speaker P “Project FORESIGHT Annual Report, 2013-2014” Forensic Science Initiative, College of Business & Economics, West Virginia University, June 2015.

⁶⁰⁵ Brady J “Federal Drug Sentencing Laws Bring High Cost, Low Return” 2015-08-27 *The PEW Charitable Trust*.

⁶⁰⁶ Zezima K and Dawsey J “Trump administration studies seeking the death penalty for drug dealers” 2018-03-09 *The Washington Post*.

error rate and has little scientific value, despite its reference in courts with regard to expert testimony. Legal professionals should also know the difference in scientific value between screening tests and confirmatory test results, and the limitations associated with each technique.

The inadequate education of lawyers and judges on how to handle expert testimony as scientific evidence is not challenged in the way it should be, neither is the dispute that develops in courts between “real experts” and “hired guns”.⁶⁰⁷ Programs should be developed, similar to the LL.M. (Legum Magister) program in Forensic Justice,⁶⁰⁸ to assist legal professionals on how to use forensic experts in criminal hearings and how science works. These programs will benefit both counsels in criminal trials and ultimately the criminal justice system as a whole. Even the NAS report in 2009 recommended to Congress that attorneys be better educated in forensic science.⁶⁰⁹ The gap has somewhat shrunk with the establishment of the National Commission on Forensic Science (NCFS) in 2013. The commission consisted of a combination of legal professionals, forensic experts, and members from academia. Before reaching its full potential, it was shut down by the Trump administration who suggested new models and a different approach.

5.7.4 Dedicated drug courts

The establishment of dedicated drug courts is not a new concept and has many advantages in the criminal justice system.⁶¹⁰ Combined team approaches and collaborations between judges,

⁶⁰⁷ Sanger RM “The Forensic Community Can Educate Lawyers, Judges” 2017-06-23 *Forensic Magazine*.

⁶⁰⁸ College of Law, West Virginia University. <https://www.law.wvu.edu/home/llm/online-llm-forensic-justice> (Date of use: 6 June 2019).

⁶⁰⁹ National Academy of Sciences 2009.

⁶¹⁰ Hoffman MB “Commentary, The Drug Court Scandal, *N.C. L. Rev* 78:1437, 1461 (June 2000). New York City is credited with using a separate court to deal with drug cases (Narcotics Courts) in 1970 [1460]. These courts were focused on managing the number of drug cases that were being introduced and not on treatment and by the 1980s these courts had taken on so many non-drug cases they had basically become traditional courts. *Id.* In the late 1980s, these courts were reconfigured and named —N Partsl and again were focused on dealing with the sheer number of drug cases in a traditional manner [1460–61]. Also, Steven Belenko Research on Drug Courts: A Critical Review 1998 (1) *NAT’L DRUG CT INST REV* 1:4 (discussing the birth of —Narcotics Courtsll in New York). Also, Vick D and Keating JL “Community-Based Drug Courts: Empirical Success. Will South Dakota Follow Suit?” 2007 *South Dakota Law Review* 52:288–90. (reviewing a history of drug courts). The first drug court with a focus on treatment was established in Dade County Miami Florida in 1989. Hoffman [1461]. Also, Belenko S and Dumanovsky T “Bureau of justice assistance US Department of Justice” 1993 Pub No NCJ-144531, Special Drug Courts: Program Brief 4. Also, Dorf MC and Fagan JA “Foreword, Community Courts and Community

prosecutors, defence counsel, probation authorities, correctional services personnel, law enforcement, pre-trial service agencies, and other service providers all contribute to successes in those communities. The Department of Justice published a report in 1997 of key components to the success in defining drug courts.⁶¹¹ Besides all other benefits in such a system, the main benefit for forensic experts and legal professionals is that the more analytical the data presented over time in court, the better the understanding of the science will be perceived by legal professionals. When various experts testify in the same court, judges as “gatekeepers” will be able to identify common aspects of similarity, understatements, and overstatements of evidence presented.

Whilst the United States served as a model in the establishment of drug courts, other countries followed and altered their own models with similar successes. The Ministry of Justice introduced dedicated drug courts in England and Wales in 2004, and in 2011 conducted a pilot evaluation process study to determine the successes of such systems in the UK.⁶¹² Again the successes were stipulated in their report on speedy trials, better rehabilitation programs, and less crime in those communities. There are currently over 1,200 counties in the United States with dedicated drug courts.⁶¹³ Legal professionals should, however, be vigilant not to get too accustomed to presiding testimony as the scientific field continuously develops with new technology and improved recommended standards. Refresher training programs should be offered to legal professionals within those dedicated systems to ensure continuous success. There should also be a commonly shared peer-reviewed journals focused on new legislation and new scientific methodology in this discipline, that will serve both professions.

Justice: Problem-Solving Courts: From Innovation to Institutionalization” 2003 *Am Crim L Rev* 40:1502–03. Also, Goldkamp JS “The Drug Court Response: Issues and Implications for Justice Change” 2000 *Alb L Rev* 63:923. Also, Vick [290]. Also, Wright M “Reversing the Prison Landscape: The Role of Drug Courts in Reducing Minority Incarceration” 2006 (8) *Rutgers Race & L Rev* 79: 88–89.

⁶¹¹ Department of Justice “Defining Drug Courts: The key components” The National Association of Drug Court Professionals, Drug Court Standards Committee, January 1997. (Reprinted in October 2004).

⁶¹² Kerr J *et al.* “The dedicated drug courts pilot evaluation process study” 2011 *Ministry of Justice Research Series 1/11 January*.

⁶¹³ Holst KYW “A Good Score? Examining Twenty Years of Drug Courts in the United States and Abroad” 2010 *Valparaiso University Law Rev* 45(1):73-106.

5.7.5 Effective supervision and human factors

Preventative action management should be a high priority in any crime laboratory. Whenever unethical decisions are made by an expert within the crime laboratory, the impact of the action goes beyond the walls of that crime laboratory. It is, therefore, important for supervisors to be vigilant with regard to the behavior of experts working under their supervision. Although forensic drug analysis is more objective in analytical data recovered, it is one of the disciplines with the highest misconduct rates than any other forensic discipline. “Dry-labbing” and “evidence disappearance” contribute to the majority of those misconduct incidents committed by forensic drug chemists. Supervisors should implement random safe audits to uncover unethical behavior, such as evidence disappearance, at earlier times.

“Dry-labbing” is one of the most difficult types of conduct to supervise unless two experts work side by side in the laboratory, or installed video surveillance within sample preparation laboratories are implemented, but this will require additional resources and justification. There is also a fine line between highly productive scientists and those taking short cuts to be noticed as a productive bench worker. Additional financial compensation plans for high performers sometimes cause higher risks for bad decision making than the purpose it was designed for. In forensic drug analysis, two areas where human factors may influence outcomes, are at sample preparation/extractions and interpretation of analytical data. Factors leading to these problems may be caused by several factors namely, exhaustion following working long extended hours in a continuing ‘back-log’ environment; boredom by doing routine work for many years without any change; overcrowded laboratory environments where more than four scientists work in the same space; low morale working environment where scientists feel unappreciated, and finally, the lack of effective supervision where they can test the boundaries without any accountability.

5.8. Conclusion

Forensic drug chemistry is setting the tone in forensic science, based on the little criticism received from the NAS and PCAST reports. Both committees applaud the discipline for sound scientific foundations it is built on. The discipline is not without its challenges and failures, but is a mature forensic science discipline and one of the areas with a strong scientific underpinning. Both fields

within the criminal justice system, science and the law, will need to continue working more closely together for future success. The gap between the law and the science in forensic drug chemistry is marginally smaller than those in other disciplines in the forensic community, but should not prevent experts in both disciplines from being vigilant and pro-active in all their efforts. The scientific methodology, if applied correctly, is valid, reliable, and repeatable. With the increase in the development of designer drugs, limitations will surface more frequently and new approaches on interpretation of spectra should be researched continuously. Data exists in crime laboratories to determine qualitative error rates and should be published on a broader level to strengthen the discipline.

Experts in the field possess the necessary scientific foundation through their qualifications and internal training programs, but effective supervision need to be reformed. Legal professionals should find ways to work more closely with scientists to exchange and find solutions between the two disciplines. Both disciplines need to establish a common dictionary or language when interacting, to ensure, for example, that words like “error” has the same meaning to both legal and scientific experts in legal proceedings.

Once the ASTM standards are approved, quality and legal authorities should make them mandatory for crime laboratories to minimise conviction of the innocent.

CHAPTER 6 From forensic serology to Deoxyribonucleic acid (DNA)

6.1 Introduction

The 1900s can be divided into two major discoveries in biological evidence. The early part of the 1900s saw the establishment of “Forensic serology”, which refers to the identification of biological evidence, including all the activities and tests associated with the evaluation and typing of such evidence in criminal matters. The second discovery happened in the early to middle 1980s with the development of forensic techniques for typing deoxyribonucleic acid (DNA). DNA replaced the classical or traditional genetic systems previously used. It will, however, be unfair if “forensic serology” is ignored in this study, as it still has applications in modern forensic biology.⁶¹⁴

6.2 Scientific development of forensic serology

During the twentieth century, further discoveries were made in respect of biological fluids, but with a focus on individuality and not just the identification of the unknown liquids. Table 6.1 below summarises the historic developments relating to scientific methods and the application thereof in forensic serology, some of which are discussed in more detail following the table.

Table 6.1 Historical development of serology in forensic science

Discovery	Scientist	Application
ABO blood system	Karl Landsteiner, 1900 Nobel Prize in Physiology or Medicine, 1930	Provided answers on why some blood transfusion were successful and others deadly. ⁶¹⁵ He mixed the red cells and serum of each of his staff and demonstrated that the serum of some people agglutinated the red cells of others. ⁶¹⁶

⁶¹⁴ Gefrides L and Welch K *The Forensic Laboratory Handbook Procedures and Practice: Forensic Biology: Serology and DNA* (Spring Link 2010).

⁶¹⁵ Schwarz HP and Dörner F “Historical Review: Karl Landsteiner and his major contributions to haematology” 2003 *British J of Haematology* 121:556–565.

⁶¹⁶ Farhud DD “A Brief History of Human Blood Groups” 2013 *Iran J Public Health* 42(1):1–6.

Immunological tests for species-specificity	Uhlenhuth's paper	Applied the immunological test to medico-legal species determination. ⁶¹⁷
	Ouchterlony's method, 1958	Introduced radial immune diffusion in agar gel RAPD-PCR or a test for species-specific mitochondrial markers.
Oxidation of Leucocytes	Kastle and Shedd, 1901	Demonstrated that enzymes will catalyse the oxidization of phenolphthalin to phenolphthalein in slightly alkaline solutions. ⁶¹⁸
AB Blood group	von Decastello and Sturli, 1902	Discovery of a fourth blood group called AB. ⁶¹⁹
Blood identification	Rudolf and Oscar Adler, 1904	Used Leucomalachite Green in blood testing. ⁶²⁰ They also introduced the use of Benzidine as a catalytic test for blood.
	Ruttan & Hardisty, 1912	Established the o-Tolidine test for blood.
	Wagenaar, 1935	Established the microcrystalline test: acetone chlor-hemin crystals.
	Ouchterlony, 1949	Established the Ouchterlony Double Diffusion technique.
	MacPhail, 1956	Discovered the MacPhails reagent.
	Owen et al., 1958	Discovered o-Dianisidine.
	Laurell, 1965	Established the Rocket Immunoelectrophoresis technique.
	Holland et al., 1974; Garner et al., 1976	Used Tetramethylbenzidine (TMB) to replace Benzidine.
	Lee et al., 1979	Used Fluorescin for the first time.
ABO blood grouping of stains	Lattes, 1916	The ABO blood group system and its usability in the examination of stains. ⁶²¹

⁶¹⁷ Department of Justice "Sourcebook in Forensic Serology, Immunology and Biochemistry" Section 3. "Determination of Species of Origin" August 1983 [133].

https://www.ncjrs.gov/pdffiles1/pr/92422_part3.pdf (Date of use: 31 January 2019).

⁶¹⁸ Department of Justice (DOJ) "Sourcebook in Forensic Serology, Immunology and Biochemistry" Unit 2 "Section 3: History and development of medico-legal examination of blood" 1983.

https://www.ncjrs.gov/pdffiles1/pr/160880_unit_2.pdf (Date of use: 7 February 2019).

⁶¹⁹ Von Decastello A, Sturli A, "Ueber die Isoagglutinine im Serum gesunder und kranker Menschen". 1902 *Mfinch med Wschr* 49: 1090–5.

⁶²⁰ DOJ "Forensic Serology" 1983.

⁶²¹ DOJ *Forensic Serology* Section 4 "Blood Grouping" 1983 [205].

	Schiff, 1924	Discovered that even dry material containing blood can be examined with regard to its ABO type using the agglutinin binding by erythrocyte membrane fragments contained in the stain eluate. ⁶²²
	Holzer, 1931	Confirmed in extensive tests the usability of the Schiff's procedure in the examination of stains and increased its practicability by introducing the pitted plate technique. ⁶²³
Luminol test	Specht, 1937	Established the presumptive test for blood. ⁶²⁴
Rhesus disease Antigen (Rh factor)	Landsteiner, 1940	Discovered that 85% of the human population carries erythrocytes that express the Rh(D) antigen, or Rhesus disease antigen. ⁶²⁵
Semen identification	Florence, 1886	First introduced the microscopic Florence Test using iodine and potassium iodide to identify choline in semen. ⁶²⁶
	Barberio, 1905	Developed a microscopic test to identify spermine in semen using a saturated solution of picric acid (Barberio test). ⁶²⁷
	Baecchi, 1909	Developed a sperm cell staining mixture of methylene blue and acid fuchsin for detection of spermatozoa in seminal fluids. ⁶²⁸
	Zernike, 1935	Invented the Phase Contrast microscope technique. Visualised the minute variation in phase as a difference in image contrast when light passed through living cells. ⁶²⁹

⁶²² DOJ *Forensic Serology* Section 19 "The ABO and Secretor Systems" 1983 [266-282].

⁶²³ Patzelt D "History of forensic serology and molecular genetics in the sphere of activity of the German society for forensic medicine" 2003 *Forensic Sci Int* 144:185-191.

⁶²⁴ Specht W "Die Chemiluminescenz des Hämins, ein Hilfsmittel zur Auffindung und Erkennung forensisch wichtiger Blutspuren" (The chemiluminescence of haemin, an aid to the finding and recognition of forensically significant blood traces) 1937 *Angewandte Chemie* 50 (8):155-157.

⁶²⁵ Landsteiner K and Weiner A "An Agglutinable Factor in Human Blood Recognized by Immune Sera for Rhesus Blood" 1940 *Exp Biol Med* 43 (1):223.

⁶²⁶ Chakraverti SN, Roy SN "Detection of seminal stains" 1938 *Indian Med Gaz Vol LXXIII* 412. <https://europepmc.org/backend/ptpmcrender.fcgi?accid=PMC5151743&blobtype=pdf> (Date of use: 7 February 2019).

⁶²⁷ DOJ *Forensic Serology* Section 19 "The ABO and Secretor Systems" 1983 [266-282].

⁶²⁸ Aggrawal A "APC *Forensic Medicine and Toxicology for Ayurveda*" (Avichal publishing company 2016).

⁶²⁹ Gundlach H "Frits Zernike and Phase Contrast Microscopy: Celebrating 50 Years of Live Cell Analysis" November 2003, *Microscopy and Analysis*.

	Bayard, 1939	Published the first reliable procedures for microscopic detection of sperm. ⁶³⁰
	Lundquist, 1945	Developed test for enzyme known as acid phosphatase. This was the first way of testing for the presence of semen and it allowed for scientists to possibly match the semen to an individual. ⁶³¹
	Berg, 1955	Developed an orientating test for sperms by examining phosphatase reactivity. ⁶³²
	Oppitz, 1969	Developed the Christmas Tree Stain (Also known as the Kernechtrot- Picroindigocarmine Stain test.) ⁶³³
	Keil, <i>et al.</i> , 1996	Succeeded in detecting seminal fluid even in cases of aspermatism making use of a monoclonal antibody against a seminal vesicle specific protein.
	Bauer and Patzelt, 2003	Detected sperms with RNA analysis using a protamine specific messenger RNA in dried stains of semen. ⁶³⁴
Sex determination of stains	Barr and Bertrams, 1949	Established the reliable identification of sex by the examination of stains started with cell-morphological sex diagnostics. Only female individuals were identifiable with the test for Barr's sex chromatin.
	Casperson ⁶³⁵ and Pearson ⁶³⁶	Identified male sex with a Y-heterochromatin test.

⁶³⁰ Irman K and Rudin N *Principles and Practice of Criminalistics: The Profession of Forensic Science* (CRC Press 2001).

⁶³¹ Jones EL "The identification of semen and other body fluids" (In: R. Saferstein (editor) *Forensic Science Handbook* (2nd ed Englewood Cliffs NJ Prentice- Hall 2005 vol 2) 329-399.

⁶³² Berg SP "A new method of testing for seminal stains" 1955 *Int Crim Police Rev* 85:53-55.

⁶³³ Aggrawal A *Forensic Medicine* 2016

⁶³⁴ Bauer M and Patzelt D "A method for simultaneous RNA and DNA isolation from dried blood and semen stains" 2003 *Forensic Sci Int* 136(1-3):76-8.

⁶³⁵ Casperson TS et al. "Chemical differentiation along metaphase chromosomes" 1968 *Exp Cell Res* 49: 219-222. Subsequent study of Casperson et al. (1969, 1970) has shown that the guanine and cytosine portions of DNA of Y chromosome emit a fluorescence, when reacted by alkylating reagent like quinacrine mustard. This binding of quinacrine mustard is due to the alkylation of guanine of Y chromosome indicating a specificity of reaction and structural difference of the Y chromosome from that of the chromosome or autosomes which do not fluoresce by quinacrine mustard.

⁶³⁶ Pearson PL "Technique for identifying Y chromosomes in human interphase nuclei" 1970 *Nature* 226: 78-80. Pearson et al. 1970 used quinacrine dihydrogen chloride 71 instead of quinacrine mustard

Differential interference contrast microscopy (DIC)	Georges Nomarski ⁶³⁷	Discovered how DIC works by separating a polarised light source into two beams, which take slightly different paths through the sample.
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6.2.1 ABO Blood System

The ABO grouping was tested for the first time in forensic science in 1901, when law enforcement discovered two disemboweled and dismembered bodies of young brothers in the forests of Rügen, Germany. Ludwig Tessnow was suspected of murdering the boys, as witnesses had earlier described Tessnow of having suspicious bloodstains on his shirt the day of the murder. The magistrate ordered the court to send the clothes of Tessnow, stained with the contaminated blood, to Paul Uhlenhuth, a professor at the University of Griefswald, Germany, to analyse it based on the ABO grouping method. By 1900, researchers at that institution had already advanced the existence of antibodies and had hypothesised about their relations to other proteins. They had developed a technique to find antibodies. Professor Uhlenhuth injected a rabbit with chicken egg proteins, extracted serum from the blood of the rabbit, and then mixed the serum with an egg white to study the serum. He discovered that the original egg proteins would clump, or precipitate out of the solution. Uhlenhuth used his new discovery to study the stains on Tessnow's shirt. He then analysed the resulting clumps and was of the opinion that the stains on the shirt were from a combination of human and sheep blood. Tessnow was convicted and executed for the murders and later became known as the Mad Carpenter.⁶³⁸

Landsteiner's discoveries of blood types brought a useable technique to forensic science practitioners. For the first time, forensic scientists could definitively compare blood evidence left at

to stain the distal half of the Y-chromosome. Since then, this dye is commonly used to locate the F-body, Y-body or Y-chromatin. Pearson et al. (1970) confirmed the finding of Vosa and were able to show that the number of fluorescent spots is increased with associated increase in the number of Y-chromosome, e.g. in XYY male, there would be two fluorescent spots.

⁶³⁷ Nomarski G, "Dispositif Oculaire a Contraste De Phase Pour Microscope," 1950 *J Phys Radium* 11:9-10.

⁶³⁸ Innes B and Singer J *DNA and Body Evidence* (Armonk NY Sharpe Focus 2008).

a crime scene to the blood of a suspect.⁶³⁹ The discovery that human blood contains antigens in red cells which vary in type among individuals in accordance with inheritance (e.g., maternal and paternal inherited genes) enabled the use of serology methods for comparative studies. The ABO gene is located on human chromosome 9 and has three main alleles, A, B and O. The ABO gene indirectly encodes the ABO blood group antigens. The A and B alleles each encode a glycosyltransferase that catalyses the final step in the synthesis of the A and B antigen. The A and B antigens are autosomal codominant. The O allele encodes an inactive glycosyltransferase that leaves the ABO antigen precursor, the H antigen unmodified.

When a blood sample mixture was tested, the sample was placed on both sides of a slide. The one side would then be exposed to anti-serum A and the other side with anti-serum B. If agglutination (clumping) occurred on either side, it would indicate either blood type A or B. If it occurred on both sides, it would be AB, and if not on either side, blood type O would be reported.⁶⁴⁰ This discovery not only assist with blood transfusions, but also became very useful in crime investigations. It set a new tone for forensic scientists to test whether or not a suspect's blood had the same pattern of clumping reactions as blood left at a crime scene. If not, scientists could inform investigators whether to exclude a suspect from further investigation.

By 1937, the continuous scientific discoveries led to the identification of more than 100 antigens and 23 different blood groups based on the presence or absence of those antigens. The simplified ABO blood typing analytical scheme remained the primary method to identify blood, because the testing for possible reactions among all known antigens were complex, time consuming, and expensive. The proportions of each blood group varied from one nation's population to another. In the United States, at the time, proportions were as follows:⁶⁴¹

- Group A, 39%

⁶³⁹ The Embryo Project Encyclopedia "ABO Blood Type Identification and Forensic Science (1900-1960)" <https://embryo.asu.edu/pages/abo-blood-type-identification-and-forensic-science-1900-1960> (Date of use: 9 September 2018).

⁶⁴⁰ DOJ *Forensic Serology* Section 19 "The ABO and Secretor Systems" 1983 [266-282].

⁶⁴¹ Innes *DNA and Body Evidence* 2008.

- Group B, 13%
- Group O, 43% and,
- Group AB, 5%

Further research showed ethnical blood grouping distribution as follows:

- Type A is more common in Caucasians and Europeans;
- Type B is more common among Africans, African descendants, and South Asia populations;
- Type AB is predominant in China, Japan, and Korea; and
- Type O is predominant in Native Americans, Aborigines, and Latin American populations, and is common among Middle-Eastern populations as well.

A small portion of the world population carries a rare variation of AB type subgroups that present weak or no reaction at all to antibodies.

After 80 years of discoveries relating to serological research, in 1983, the U.S. Department of Justice published a complete sourcebook, titled "Sourcebook in Forensic Serology, Immunology, and Biochemistry". The sourcebook was compiled and edited by Gaensslen,⁶⁴² and contained a vast collection of published papers on serological developments and their use in criminal investigations. With the introduction of each new methodology, legal challenges followed. The next section will discuss early use and challenges in legal proceedings.

6.3 First legal challenges to the scientific method related to serology

As blood typing became more known in legal settings, courts were ambivalent to implement compulsory blood typing in paternity, criminal, and personal injury cases due to a Supreme Court ruling in 1891 in Washington DC. In the case of *Union Pacific Railroad v. Botsford*,⁶⁴³ the court held that case law at the time did not compel individuals to submit to physical examinations, which

⁶⁴² DOJ "Forensic Serology" 1983.

⁶⁴³ *Union Pacific Railway Co. v. Botsford*, 141 U.S. 250 (1891).

compulsory blood typing on insistence of other parties would require. In 1934, in the case of *Beuschel v. Manowitz*,⁶⁴⁴ an appellate court in Brooklyn, New York, reversed a decision of the district's trial court that had ordered a woman and her child to provide blood samples for blood group tests. The appellate court reversed the order even though the New York legislature had passed laws to allow compulsory physical exams. The following year, the New York legislature responded to the case of *Beuschel v. Manowitz* by passing a statute that allowed courts to require blood group testing in civil cases. Later the same year, in the case of *Flippen v. Meinhold*,⁶⁴⁵ a New York City court maintained that the blood grouping tests would be improper for drawing an inference of paternity, as even a positive result would furnish no satisfactory proof of defendant's paternity. The court ruled that the application did not fall within the scope of section 306a of the Civil Practice Act,⁶⁴⁶ which was clearly intended to be used as a shield and not as a sword, and denied the request.

The science behind blood grouping became more refined and acceptable universally, and individual states in the United States started to acknowledge the value of blood grouping reflected in those developments. Litigation changes allowed courts to order witnesses, in both criminal and civil trials, to submit to compulsory blood group testing.

In the case of *Raymond H. Groulx v. Rose Gregoire Groulx*,⁶⁴⁷ a legal proceeding involving the legitimacy of a child, the Supreme Court of New Hampshire acknowledged that developments in science enable qualified experts to conduct accurate blood group testing to disprove paternity in cases. Since the first reported American case on a blood grouping test in 1931, there had been steady and increasing judicial recognition of the accuracy and reliability of such tests, but also

⁶⁴⁴ *Beuschel v. Manowitz* 241 App. Div. 888 (N.Y. App. Div. 1934).

⁶⁴⁵ *Flippen v. Meinhold* 156 Misc. 451 (N.Y. Misc. 1935).

⁶⁴⁶ New York Public Law "New York Civil Practice Law Sec. 306-A Index Number in an Action or Proceeding Commenced in Supreme or County Court"
https://newyork.public.law/laws/n.y._civil_practice_law_section_306-a (Date of use: 22 June 2018).

⁶⁴⁷ *Raymond H. Groulx v. Rose Gregoire Groulx*, 98 N.H. 481 (1954).

judgments to the contrary in other jurisdictions.^{648, 649, 650} In *Groulx v. Groulx* the court further stated that:

“While New Hampshire had adopted the Uniform Act on Blood Tests to Determine Paternity (Laws 1953, c. 126) it cannot control the determination of this case which was heard and decided before the enactment of that statute. However, it may be noted that scientific and medical evidence from qualified experts is generally accepted in this jurisdiction in both criminal and civil cases. *State v. Baron*, 98 N. H. 298; *Bohan v. Company*, 98 N. H. 144, 147. Whatever defects there may be in this trend it at least avoids the common criticism made elsewhere that “. . . trial courts have tended to lag far behind” in utilizing probative methods developed by medicine and science. Maguire, *Evidence, Common Sense and Common Law* (1947) 30. It is unnecessary to decide in this case whether the blood grouping tests should be regarded as conclusive or only evidentiary, since *Saunders v. Fredette*, 84 N. H. 414, establishes the rule that the presumption of legitimacy need not be rebutted by conclusive evidence but may be rebutted by clear and convincing proof. This brings us to a consideration of the blood grouping tests used in this proceeding.” [...]

After Dr. Allen's report was received by the court, Dr. A. S. Wiener of New York, a leading authority in blood grouping tests, wrote Dr. Allen that his conclusions as to exclusion of paternity based on the S factor alone were “too strongly worded.” Thereupon Dr. Allen modified his original opinion in some details as appears in the statement of facts but reaffirmed his essential conclusion as appears from the following concluding paragraph: “My personal opinion is that exclusion of paternity is demonstrated by the tests with anti-S, as stated in my original report, and that the evidentiary value of my tests is greater than any other biologic tests which might be done in this particular case at the present time. This letter is written to make it clear that this is my personal opinion, which might, or might not, be fully shared by Dr. Wiener. In order not to jeopardize the future value of tests with anti-s in legal cases, I should have to testify that the tests done in this case with anti-s do not absolutely exclude paternity, because of the present lack of a sufficient body of genetic data.” Whether Dr. Allen discussed the matter by telephone with Dr. Wiener as the latter suggested does not appear from the record.

The Trial Court interpreted Dr. Wiener's letter as being primarily concerned with the effect that Dr. Allen's strongly worded report would have “on medicolegal blood grouping tests”

⁶⁴⁸ *Commonwealth v. Zammarelli*, 1931, 17 Pa. D. & C. 229.

⁶⁴⁹ *Jordan v. Mace*, 144 Me. 351; Anno. 163 A. L. R. 939.

⁶⁵⁰ Some of the earlier authorities are collected and analyzed in I Wig., Ev. (3rd ed 1940) ss. 165a, 165b. Also, Schatkin SB *Disputed Paternity Proceedings* (1st ed Matthew Bender Elite Products 1944). Wig “*Science of Judicial Proof*” (3rd ed 1937) 88-90. Also, Maguire JM “A Survey of Blood Group Decisions and Legislation in the American Law of Evidence” 1943 (16) *Southern California Law Rev* 161. It is true that in some jurisdictions the reliability of blood grouping tests has been disregarded (*Arais v. Kalensnikoff*, 10 Cal.2d 428; *Berry v. Chaplin*, 74 Cal. App. 2d 652) but these decisions are not representative of the modern rule today. Harper “Problems of the Family” 1952 (29) *N. D. Law Rev.* 156 112-114 (1953). Also, 1952 (50) *Mich Law Rev* 582.

and not indicating that the tests were entitled to no evidentiary value. See the report of Dr. Wiener and others entitled, "Medicolegal Application of Blood Grouping Tests" 149 Journal, American Medical Association (June 14, 1952) 699. We conclude that the blood grouping tests in this case were entitled to evidentiary weight even though they do not have the benefit of the full genetic data that is available in the more common blood groups such as A-B-O, M-N and Rh-Hr. See Andresen, *The Human Blood Groups* (1952) 43. In this respect the blood grouping tests were like other expert opinion evidence and entitled to such weight as the Trial Court wished to give them. See *Ricard v. Insurance Co.*, 87 N. H. 31, 36.⁶⁵¹(emphasis added)

From the appeal it was clear that scientists were already accused by fellow scientists of overstating the value of evidence. The value of such weight should have been left to the court to decide.

By the 1960s, forensic scientists could use ABO blood group testing to confidently exclude individuals as the sources of blood sample evidence on crime scenes, but they could provide only statistical probabilities by which to include individuals as the sources of blood sample evidence. For example, if B-type blood was left at the scene of a crime, a scientist could only say that a individual with O, A, or AB-type blood did not leave the blood evidence, and that the blood could have come from any individual of the population with B-type blood, which constituted 13 per cent of the overall population. Scientists could use blood-typing, therefore, to help prove innocence, but they could not use it to help identify an individual beyond a reasonable doubt, the standard necessary for a criminal conviction in majority of jurisdictions.⁶⁵²

After 80 years of discoveries made in serology, the dynamics were about to change with the discovery of deoxyribonucleic acid.

6.4 The dynamic change in forensic biology

6.4.1 Discovery of Deoxyribonucleic acid (DNA)

Although the application of DNA in forensic science only started in the early 1980s, it was Oswald Avery who defined the role of the cellular component known as DNA (deoxyribonucleic acid) as the vehicle of generational transference of heritable traits in 1944. In 1953, James Watson and

⁶⁵¹ *Groulx v. Groulx* 98 NH 481, 103 A. 2d 188 - NH: Supreme Court, 1954.

⁶⁵² Maiste P *Probability and Statistics for Bioinformatics and Genetics* (Johns Hopkins University 2006).

Francis Crick elucidated the structure of the DNA molecule as a double helix. Their paper was submitted to *Nature* and published in April, 1953.⁶⁵³ In science, as in art, form follows function; the very nature of the molecule provided an explanation for its unique properties, including the ability to propagate itself faithfully from generation to generation.⁶⁵⁴ In 1962 they received the Nobel Prize for their discovery.

In 1975, Edward Southern published a paper describing a method to locate a particular sequence within a mixture and then transfer the fragmented DNA sequence from agarose gels to cellulose nitrite filters. The fragments could then be hybridised to radioactive DNA and hybrids detected by radio autography or fluorography. The method was illustrated by analysis of restriction fragments complementary to ribosomal RNAs from several mammals.⁶⁵⁵ This process was later known as Southern Blotting.

6.4.2 Application and timeline discoveries in forensic biology

The 1980s marked the start of a paradigm shift in forensic biology. What was considered confirmatory testing when performing ABO grouping, changed to presumptive testing with the discovery of DNA. The discoveries can be classified into five main areas for DNA research, namely extraction, quantitation, amplification, capillary electrophoresis (CE), and analysis. Before these areas are discussed in more detail, it would be important to know the foundational discoveries with associated terminology used in the biological community. Table 6.2 provides a timeline of discoveries within DNA analysis.

⁶⁵³ Watson JD and Crick F "*Molecular Structure of Nucleic Acids: A Structure for Deoxyribose Nucleic Acid.*" 25 April 1953 *Nature* 171: 4356:737-738.

⁶⁵⁴ Watson *Molecular Structure* 1953.

⁶⁵⁵ Southern EM "Detection of Specific Sequences among DNA fragments separated by Gel Electrophoresis" 1975 *J Mol Biol* 98:503-517.

Table 6.2 Timeline of relevant scientific discoveries in DNA analysis

Discovery	Scientist/ Date	Discovery value
Restriction Fragment Length Polymorphism (RFLP)	White, ⁶⁵⁶ 1980	A restriction fragment is a part of DNA that is excised from the larger molecule by a protein called a restriction enzyme or restriction endonuclease. ⁶⁵⁷ This method uses sequence polymorphisms.
Polymerase Chain Reaction (PCR)	Mullis, ⁶⁵⁸ 1983	A heating and cooling process used to exponentially amplify DNA. A process to start and stop DNA polymerase action and repeating numerously, a way of exponentially amplifying a DNA sequence.
PCR improvements	Hongbao, ⁶⁵⁹ 2005	PCR improvement from 1983 to 2006.
Short Tandem Repeats (STR)	Edwards <i>et al.</i> , ⁶⁶⁰ 1991 Tautz, and Schlotter, ⁶⁶¹ 1994	DNA typing and genetic mapping with di-, tri-, tetra-, penta-, and hexanucleotide repeats. This type of polymorphism is a length polymorphism. Simple sequence repeats.
Population Genetics	Bowcock <i>et al.</i> , ⁶⁶² 1994	High resolution of human evolutionary trees with polymorphic microsatellites.
Micro-satellites or Short Tandem Repeats (STRs)	Petes <i>et al.</i> , ⁶⁶³ 1997 Wierdl <i>et al.</i> , ⁶⁶⁴ 1997	Provided systems that made examination of stains practicable for forensic applications by allele sequence analysis and optimisation of methods. STR typing was more sensitive than single-locus RFLP

⁶⁵⁶ Botstein D *et al.* "Construction of a genetic linkage map in man using restriction fragment length polymorphisms" 1980 *Am J Hum Gen* 32 (3):314–331.

⁶⁵⁷ Williams RC *Restriction Fragment Length Polymorphism (RFLP)* (Yearbook of physical Anthropology 32:1989).

⁶⁵⁸ Bartlett JMS and Stirling D *A short history of the Polymerase Chain Reaction* (PCR Protocols 2nd ed Humana Press *Methods in Molecular Biology* Volume 226 2003).

⁶⁵⁹ Hongbao M "Development Application of Polymerase Chain Reaction (PCR)" 2005 *J Am Sci* 1(3):1-47.

⁶⁶⁰ Edwards AI *et al.* "DNA typing and genetic mapping with trimeric and tetrameric tandem repeats" 1991 *Am J Hum Gen* 49:746-756.

⁶⁶¹ Tautz D and Schlotterer C "Simple sequences" 1994 *Curr Opin Gen Dev* 4:832-837.

⁶⁶² Bowcock AM *et al.* "High resolution of human evolutionary trees with polymorphic microsatellite" 1994 *Nature* 368:455-45.

⁶⁶³ Petes TD *et al.* "Stabilization of microsatellite sequences by variant repeats in the yeast *Saccharomyces cerevisiae*" 1997 *Genetics* 146:491-498.

⁶⁶⁴ Wierdl M *et al.* "Microsatellite instability in yeast: dependence on the length of the microsatellite" 1997 *Genetics* 146:769-779.

		methods, less prone to allelic dropout than VNTR systems, and more discriminating than other PCR-based typing methods.
Y-STR haplotyping	Roewer <i>et al.</i> ⁶⁶⁵	A method used to detect and differentiate male DNA.
Mitochondrial DNA	Nass and Nass ⁶⁶⁶	Mitochondrial DNA (mtDNA or mDNA) is the DNA located in mitochondria, cellular organelles within eukaryotic cells.
	Haslbrunner <i>et al.</i> ⁶⁶⁷	Biochemical assays on highly purified mitochondrial fractions.

The abovementioned discoveries formed the foundation of DNA identification as we know it today. During the 10th International Congress of the Society for Forensic Haemogenetics, it was suggested using RFLP determination by hybridisation to specific probes following DNA digestion. Although the method demonstrated the ability to determine greater variability at specified *loci* (previously not possible with blood group analysis), scientists did not see the potential for reaching individuality.⁶⁶⁸ The reason for skepticism was that 99.9 % of the DNA from two people will be identical. The remaining 0.1% of DNA contain sequences that vary from person to person are what make individuals unique. These sequences, called genetic markers, were used by forensic scientists when doing a DNA test. Furthermore, together with this low variation, identical twins will have identical genetic markers, and the more closely related two people are, the more likely it is that some of their genetic markers will be similar.

The key to the successful discovery of these small differences for scientists who researched DNA sequencing, was to know where to look in the billions of letters of genetic code to find the genetic markers that will identify the important similarities or differences among individuals. The DNA molecules in the 23 pairs of human chromosomes contain approximately 3.3 billion base pairs. It

⁶⁶⁵ Roewer L *et al.* "Simple repeat sequences on the human Y chromosome are equally polymorphic as their autosomal counterparts" 1992 *Hum Gen* 89:389–394.

⁶⁶⁶ Nass MM and Nass S "Intermitochondrial fibres with DNA characteristics" 1936 *J Cell Biol* 19:593-629.

⁶⁶⁷ Talwar P Manual of Cytogenetics in Reproductive Biology (Jaypee Brothers Medical 2014).

⁶⁶⁸ Driesel AJ "Genetisch determinierte Variabilität von DNA-segmenten" (In: Proceedings of the 10th International Congress of the Society for Forensic Haemogenetics 1983) 283–288.

would be neither feasible nor necessary to attempt reconstructing an individual's entire genome in forensic profiling. Only a small number of regions are sampled for forensic identification, known as *loci* (single, *locus*). For forensic profiling it was the non-coding regions with greater variations than coding regions, which was suitable for forensic work. Values for short tandem repeats (STRs), which are short sequences of base pairs repeated multiple times, could be expressed in forensic DNA profiles. Variability is found at regions known as polymorphic sites and each arrangement of base pairs that occurs at a polymorphic site is referred to as an allele. Alleles can result from differences in a single base pair, differences in multiple base pairs, or differences in the number of base pairs that comprise a site. The combination of alleles from these corresponding sites on a chromosome pair is referred to as the site's genotype. A genotype at a *locus* consists of two STR values, one for the allele inherited from the father and one for the allele inherited from the mother. If these alleles have two different values, the person is said to be heterozygous at that *locus*. If the values for the two alleles happen to be the same, the person is homozygous at that *locus*.

Although Mullis discovered PCR⁶⁶⁹ in 1983, it was only in 1989 that the Cetus Company finally obtained the patent for the PCR technique. The enzyme molecule used in polymerase chain reaction (PCR) was named as *Thermus aquaticus* (*Taq*) Polymerase. PCR mimics the cell's ability to replicate DNA—enabling scientists to take small samples of DNA and essentially copy it a million fold. PCR technology had similar basic steps to RFLP—extraction, amplification and detection. PCR was and still is a method to amplify chosen DNA sequences *in vitro* as much as desired. Mullis received the Nobel Prize in discovery of PCR in 1993.

PCR amplification allowed production of many copies of the region of DNA interest. PCR worked like a “molecular Xerox copier.” Millions of copies of a particular sequence of DNA could be made in less than three hours in a thermal cycler. This was great for forensic science when there is very little DNA to start with. Besides the high environmental stability and the content of information, this feature of DNA was the reason that DNA analysis had revolutionised the forensic examination of stains. This technique was first revealed to the world at a conference in 1985 and was widely accepted by the scientific community after then. Later, in the early 1990s, Roche Molecular (Perkin

⁶⁶⁹ Bartlett “A short history of PCR” 2003.

Elmer) developed two PCR-based analysis kits, namely, HLA DQ Alpha^{670,671} and Poly Marker⁶⁷² that led to further research on interpretation and population studies. Early studies showed both methods had disadvantages with regard to DNA mixtures.

Since the mid-1990s until 2004, more than 2,000 publications appeared, detailing the technology, hundreds of different population groups that have been studied, new technologies, for example, the mini-STRs⁶⁷³ that have been developed, and standard protocols that have been validated in laboratories across the globe. All of this was captured in a book by Dr. Johnathan Butler, a well-known researcher working at the National Institute of Standards and Technology (NIST).⁶⁷⁴

6.4.3 Application of DNA in forensic science

It was, however, the geneticist Sir Alec Jeffreys and colleagues at the University of Leicester, United Kingdom who made the first breakthrough when he discovered in 1984 a unique application of RFLP technology while searching for disease markers in DNA.⁶⁷⁵ He realised the method could be used for personal identification. By developing a technique to examine the length variation of DNA repeating sequences, he created a method to perform human identity tests. The DNA repeat regions (VNTRs) could be examined by using RFLP, because it involved the use of a restriction enzyme to cut regions of DNA surrounding the VNTRs. His method, which he termed “DNA fingerprinting,” was modified to detect *loci* sequentially rather than concomitantly, and soon after the discovery, the technique was researched more and adopted by crime laboratories internationally.⁶⁷⁶ The technique proved applicable in many biological disciplines, namely in diversity and conservation studies among species, and in clinical and anthropological studies. In

⁶⁷⁰ Comey CT *et al.* “PCR amplification and typing of the HLA DQ alpha gene in forensic samples” 1993 *J Forensic Sci* 38(2):239-49.

⁶⁷¹ Crouse CA *et al.* “Analysis and interpretation of the HLA DQ alpha ‘1.1 weak-signal’ observed during the PCR-based typing method” 1994 *J Forensic Sci* 39(1): 41-51.

⁶⁷² Garofano L *et al.* “Italian population data on the polymarker system and on the five short tandem repeat loci CSF1PO, TPOX, TH01, F13B, and vWA” 1998 *J Forensic Sci* 43(4):837-40.

⁶⁷³ Coble MD and Butler JM “Characterization of new miniSTR loci to aid analysis of degraded DNA” 2005 *J Forensic Sci* 50:43–53.

⁶⁷⁴ Butler JM *Forensic DNA Typing: Biology, Technology, and Genetics of STR Markers 2* (New York: Elsevier Academic Press 2005).

⁶⁷⁵ Jeffreys AJ *et al.* “Individual-specific fingerprints of human DNA” 1985 *Nature* 316:76-79.

⁶⁷⁶ Jeffreys “Human DNA” 1985.

the forensic community, it was first defined as a forensic genetic fingerprinting technique focusing on comparison of the DNA in an individual's nucleated cells with those identified in biological matter found on a crime scene.⁶⁷⁷

A series of publications^{678,679} under the supervision of Sir Jeffreys, followed, focused on gaining a better understanding of the use of the technique in crime laboratories. Scientists also agreed that better descriptive and inclusive wording to use, would be "DNA typing" or "DNA profiling".⁶⁸⁰ With this wording change, the discipline made a clear separation, by association, from any other discipline in forensic science, for example, latent fingerprints. DNA profiling evolved into a forensic empire in the forensic community, and was soon thereafter seen as the "new gold standard" in forensic science. Even with this entitlement, the field continued to apply more research to find better ways in extraction, quantitation, amplification, analysis and interpretation, with a more comprehensive statistical foundation in interpretation.

Forensic DNA profiling could be completed using a panel of multi-allelic STR markers, which are structurally analogous to the original mini-satellites, but with notable shorter repeat tracts and thus less complicated to amplify and multiplex with PCR.⁶⁸¹ Up to 24 STRs could be observed in a single capillary electrophoresis injection, thus generating a unique DNA profile for each individual. There were basically two sets of STR markers complying with the standards requested by criminal databases around the world:

- European standard set of 12 STR markers⁶⁸² and
- US CODIS standard of 13 STR markers.⁶⁸³

⁶⁷⁷ Roewer L "DNA Fingerprinting in forensics: past, present, future" 2013 *Investing Gen* 4:22.

⁶⁷⁸ Gill P *et al.* "Forensic application of DNA fingerprints" 1985 *Nature* 318: 577-579.

⁶⁷⁹ Wong Z *et al.* "Characterization of a panel of highly variable mini-satellites cloned from human DNA" 1987 *Ann Hum Gen* 51:269-288.

⁶⁸⁰ Norah R and Irman K *Forensic DNA analysis* (CRC Press 2nd ed 2001).

⁶⁸¹ Roewer "DNA fingerprinting" 2013.

⁶⁸² Gill P *et al.* "The evolution of DNA databases - Recommendations for new European STR loci" 2006 *Forensic Sci Int* 156:242-244.

⁶⁸³ Budowle B *et al.* *CODIS and PCR-based short tandem repeat loci: law enforcement tools* (Madison WI: Promega Corporation 1998) 73-88.

Due to partial overlap, together they formed a standard of 18 STR markers in total. The inclusion of these STR markers into commercially manufactured kits had enhanced the application of these markers for all kinds of DNA evidence with reproducible results from as few as three nucleated cells,⁶⁸⁴ and could be extracted even from severely compromised evidence. The probability that two individuals had identical markers at each of 13 different STR *loci* within their DNA, exceeds one out of a billion. If a DNA match occurred between an individual and a crime scene stain, the correct statistical expression used in court was that the probability of a match if the crime-scene sample came from someone other than that individual (considering the random, not closely-related man), is at most one in a billion.⁶⁸⁵

Also discovered during the research time was that lineage markers had unique applications in forensic genetics. The use of Y-chromosome analysis in cases where there was an excess of DNA from a female victim and only a low proportion from a male perpetrator was very helpful. Typical examples included sexual assault without ejaculation, sexual assault by a vasectomised male, male DNA under the finger nails of a victim, male “touch” DNA on the skin, and the clothing or belongings of a female victim. Mitochondrial DNA (mtDNA) was discovered to be of importance for the analyses of low level nuclear DNA samples, namely from unidentified (typically skeletonised) remains, hair shafts without roots, or very old specimens where only heavily degraded DNA was available.⁶⁸⁶ A classic case in this regard was the identification of two missing children of the Romanov family, the last Russian monarchy. MtDNA analysis, combined with additional DNA testing of collected samples from the mass grave near Yekaterinburg, provided virtually irrefutable evidence that the two individuals recovered from a second grave nearby were the two missing children of the Romanov family: Tsarevich Alexei and one of his sisters.⁶⁸⁷

⁶⁸⁴ Nagy M *et al.* “Optimization and validation of a fully automated silica-coated magnetic beads purification technology in forensics” 2005 *Forensic Sci Int* 152:13–22.

⁶⁸⁵ Jobling MA *et al.* *Human Evolutionary Genetics*. Abingdon: Garland Science (2003. Chapter 15 *Identity and identification*) 474–497.

⁶⁸⁶ Roewer L and Parson W *Encyclopedia of Forensic Sciences 2* (Siegel JA, Saukko PJ editors Amsterdam: Elsevier BV 2013).

⁶⁸⁷ Coble MD *et al.* “Mystery solved: the identification of the two missing Romanov children using DNA analysis” 2009 *NCBI PLoS One* 4(3):4838.

A research survey on the use of Y-chromosome typing in forensic analysis showed a wide acceptance in the community, especially with the introduction of highly sensitive panels of up to 27 STRs including rapidly mutating markers.⁶⁸⁸ The determination of the match probability between Y-STR or mtDNA profiles via the mostly applied counting method⁶⁸⁹ required large, representative, and quality-assessed databases of haplotypes sampled in appropriate reference populations, because the multiplication of individual allele frequencies were not as valid as for independently inherited autosomal STRs.⁶⁹⁰ Other estimators for the haplotype match probability other than the count estimator had been proposed and evaluated using empirical data.⁶⁹¹ However, the biostatistical interpretation remained complicated and controversial as research continued.

Along with the implementation of the new technique, new challenges and extended applications arose soon after it was put to the test for use and recognition in legal proceedings.

6.5 First legal challenges to the scientific method related to DNA

6.5.1 First civil court challenge on DNA analysis

When first introduced to the criminal justice system and law enforcement, prosecutors, defence counsel and judges struggled with the terminology and the ideas of molecular biology, genetics, and statistics. The only way to overcome the struggle was to put it to the test. The first DNA test case arose in 1985, although not strictly with regard to forensic science, but concerning an immigration challenge instead.

In April 1985, Sir Alec Jeffreys, then a professor at Department of Genetics at the University of Leicester (Leicester, United Kingdom), received a letter from Sheona York, a London lawyer. York

⁶⁸⁸ Ballantyne KN *et al.* "A new future of forensic Y-chromosome analysis: rapidly mutating Y-STRs for differentiating male relatives and paternal lineages" 2012 *Forensic Sci Int Gen* 6:208–218.

⁶⁸⁹ Budowle B *et al.* "Utility of Y-chromosome short tandem repeat haplotypes in forensic applications" 2003 *Forensic Sci Rev* 15:153–164.

⁶⁹⁰ Roewer L *et al.* "A new method for the evaluation of matches in non-recombining genomes: application to Y-chromosomal short tandem repeat (STR) haplotypes in European males" 2000 *Forensic Sci Int* 114:31–43.

⁶⁹¹ Andersen MM *et al.* "Estimating trace-suspect match probabilities for singleton Y-STR haplotypes using coalescent theory" 2013 *Forensic Sci Int Gen* 7:264-271.

was faced with a tricky immigration dispute involving a family from Ghana, and read about the work of Jeffreys on DNA fingerprinting. The youngest boy of the family went back to Ghana for a visit and on his return to the United Kingdom, immigration authorities suspected that his passport had been tampered with. The authorities believed that he was a non-citizen substitute and denied him access. With multiple DNA testing, in the absence of the biological father but with DNA from three other siblings from the same mother, Sir Jeffreys showed that every genetic character of the disputed boy matched the mother or father.⁶⁹² As a result, the immigration tribunal dropped the case and allowed the boy back into the United Kingdom as a full citizen. The technique saved a young boy from deportation, capturing the sympathy of the public.⁶⁹³ Sir Alec Jeffreys stated as follows in an interview in 2004:

“If our first case had been forensic I believe it would have been challenged and the process may well have been damaged in the courts”.⁶⁹⁴

6.5.2 First criminal court challenge on DNA analysis

The first well known case of forensic DNA application was that of Colin Pitchfork, who went on trial in 1987 for the rape and murder of Lynda Mann (1983) and Dawn Ashworth (1986). On 21 November 1983, 15-year-old Lynda Mann did not return home after visiting a friend in the village of Narborough, south of Leicester, England. Her naked body was found on a lonely footpath, called the “Ten Pound Lane”, two days later. A post-mortem revealed that she had been raped and strangled, and a semen sample was retrieved from her body. Investigators could not find any other clues and the case went cold, although the file was never closed. A few years later, on 31 July 1986, another 15-year-old girl, Dawn Ashworth, disappeared on her way home. Her raped, beaten and strangled body was discovered in a wooded area two days later. A semen sample was discovered on her body. Initially police believed the rapist and murderer was 17-year-old Richard Burkland who appeared to have knowledge of Dawn’s body and even admitted to the crime under questioning. Using the newly developed method by Sir Alec Jeffreys, a DNA profile was produced from the semen sample. However, the two semen sample profiles did not match that of Burkland.

⁶⁹² Jeffreys AJ *et al.* “Positive identification of an immigration test-case using human DNA fingerprints” 1985 *Nature* 317:818-819.

⁶⁹³ Jeffreys “Immigration test” 1985.

⁶⁹⁴ University of Leicester Bulletin Supplement August/September, 2004.

This led to another cold case, but this time the Leicestershire Constabulary and the Forensic Science Service teamed up to conduct a project in which 5000 local men were asked to give a blood or saliva sample for DNA testing for comparison with the suspect's DNA profile. After thousands of samples were analysed over six months, no matches were found. During this period, a local man, Ian Kelly bragged about how he received £200 to give a DNA sample on behalf of his friend, Colin Pitchfork. On 19 September 1987, Pitchfork was arrested. A DNA sample was taken, which matched the two semen crime scene samples. He admitted to the rape and murder of the two girls. Pitchfork became the first person in the world to be identified, captured and successfully prosecuted as a result of DNA evidence.⁶⁹⁵ The outcome of the case spread like a bush fire in high winds through international jurisdictions and court corridors.

6.5.3 First case of DNA evidence admissibility in the United States

The first case of admissibility of DNA evidence in the United States in 1987 arose from the conviction of Tommie Lee Andrews of rape after DNA tests matched his DNA from a blood sample with that of semen traces found in a rape victim. His fingerprints were also found on a window frame outside the dwelling. It was the first use of DNA profiling in the United States and took place in Orange County, Florida. The case went on appeal in *Tommie Lee Andrews, v. State of Florida*.⁶⁹⁶ The accused's defence contested the new scientific method and stated the following:

“The issue in this case concerns the admissibility of ‘genetic fingerprint’ evidence, by which strands of coding found in the genetic molecule of deoxyribonucleic acid (DNA) are compared for the purpose of identifying the perpetrator of a crime. The trial court admitted the evidence, and the jury convicted defendant of aggravated battery, sexual battery and armed burglary of a dwelling. We conclude that the evidence was properly admitted and that defendant's other issues are without merit, and we affirm.”

Judge Orfinger admitted that some uncertainty existed as to the standard applicable in the State of Florida governing admissibility into evidence of a new scientific technique. He also referred to

⁶⁹⁵ Wambaugh J “*The Blooding: The True Story of the Narborough Village Murders*” 1989 Morrow; New York. Also, <http://aboutforensics.co.uk/colin-pitchfork/> (Date of use: 22 July 2018).

⁶⁹⁶ *Tommie Lee Andrews, v. State of Florida*, No. 87-2166, District Court of Appeal of Florida, Fifth District on October 20, 1988.

the case of *Frye v. United States*,⁶⁹⁷ which involved the question of admissibility of lie detector test results. Judge Van Orsdel, in *Frye v United States*, stated that expert testimony relating to novel scientific evidence must satisfy a special foundational requirement not applicable to other types of expert testimony:

“Just when a scientific principle or discovery crosses the line between the experimental and demonstrable stages is difficult to define. Somewhere in the twilight zone the evidential force of the principle must be recognized, and while the courts will go a long way in admitting expert testimony deduced from a well-recognized scientific principle or discovery, the thing from which the deduction is made must be sufficiently established to have gained general acceptance in the particular field to which it belongs”.⁶⁹⁸

Discussing the issue of relevancy, Judge Orfinger referred to the case of *United States v. Downing*.⁶⁹⁹

“In *Downing*, the Third Circuit, in applying a relevancy/reliability approach, declared that where, as here, a form of scientific expertise has no established ‘track record’ in litigation, courts may look to a variety of factors that may bear on the reliability of the evidence. 753 F.2d at 1238. These include the novelty of the new technique, i.e., its relationship to more established modes of scientific analysis, the existence of a specialized literature dealing with the technique, the qualifications and professional stature of expert witnesses, and the non-judicial uses to which the scientific technique are put. *Id.* at 1238-39, citing 3 J. Weinstein & M. Berger, *Weinstein's Evidence* § 702[03].”

Judge Orfinger noted that in applying the relevancy test, it seems clear that the DNA print results would be helpful to the jury. All evidence, the novelty of DNA and its reliability, were justified during the trial. Judge Orfinger denied a rehearing on November 22, 1988.⁷⁰⁰ This case opened more doors for the admissibility of DNA in criminal trials and experts were allowed to present the evidence to juries.

⁶⁹⁷ *Frye v. United States*, 293 F. 1013 (D.C. Cir.1923).

⁶⁹⁸ *Frye* [1014].

⁶⁹⁹ *United States vs. Downing*, 753 F.2d 1224 (3d Cir.1985).

⁷⁰⁰ *Tommie Lee Andrews* 1988.

6.5.4 Comprehensive challenges on DNA evidence admissibility

6.5.4.1 *People v. Castro*

A more comprehensive challenge regarding the admissibility of DNA evidence in a trial was raised in the case of *People v. Castro*.⁷⁰¹ It was alleged that on February 5, 1987, Joseph Castro, stabbed 20-year-old Vilma Ponce, who was seven months' pregnant at the time, and her 2-year-old daughter, to death. A wristwatch worn by him at the time of his arrest was seized. What appeared to be bloodstains on the watch, were noted by the detectives. The defendant stated that the blood was his own. The pre-trial hearing took twelve weeks whereby the New York Supreme Court exhaustively examined numerous issues relating to the admissibility of the DNA evidence. Attorney Barry Scheck, who at the time represented the Public Defender's office and is now the director of the Innocence Project, challenged the science of DNA evidence, which resulted in a number of pre-trial hearings. The hearings were required to determine whether the testing laboratory's methodology was substantially in accordance with scientific standards and produced reliable results for jury consideration. The defence literally put DNA fingerprinting on trial. The defendant was able to disclose severe insufficiencies in the technical protocols and especially in the DNA evidence interpretation. These raised doubts on the scientific and evidentiary value of forensic DNA fingerprinting. Despite this, however, Judge Sheindlin stated:⁷⁰²

“Accordingly, to breathe any meaning into the opinion of these highly respected and rather brilliant scientists one must conclude that the test is presently reliable and will remain so for the next six months. Therefore, it is the conclusion of this court that DNA forensic identification tests to determine inclusions are reliable and meet the Frye standard of admissibility.”

Judge Gerald J. Sheindlin subsequently ruled that the DNA results could be used to indicate that the blood on Castro's watch was not his; but the results could not be used to show that the blood was that of Vilma Ponce. Regardless of the restriction placed on the state, Joseph Castro was found guilty on all charges.

⁷⁰¹ The People of the State of New York, v. Joseph Castro, Supreme Court, Bronx County. August 14, 1989.

⁷⁰² *Castro* [973].

The following conclusions regarding the early use of DNA evidence could be drawn from the above judgment:

- Despite the challenge by the defence to discredit the novel science, DNA technology was foundationally proven to be valid.
- The “Lifecodes” tests showed that the blood was from the victim and was admitted by the defendant.
- The judge allowed the admission for exclusion testimony after endorsing the scientific foundation of DNA profiling.
- Procedural problems by the expert led to the inadmissibility of evidence that the blood matched the victim.

These conclusions clearly indicate that science prevailed at the time.

6.5.4.2 *United States v. Randolph Jacobetz*

Another admissibility challenge arose in 1991 in the appeal case of *United States v. Randolph Jacobetz*.⁷⁰³ The appellant complained of several evidentiary rulings, the most important of which is the court's permitting of DNA profiling evidence. Jacobetz was found guilty in October, 1990 for the kidnapping and rape of a young woman from Burlington, Vermont. She was grabbed from the back at a rest area along Interstate 91 in Westminster, Vermont. Jacobetz handcuffed his victim, stuffed her mouth with paper towels, and covered her head with a pillowcase before forcing her into the back of his tractor trailer in the early morning hours of June 14th, 1989. After driving for half an hour, he stopped and repeatedly raped her before driving for another couple of hours before releasing her on the roadside in the Bronx, New York. A DNA semen sample that was tested came from a swab from the victim. The court heard testimony from five government experts and four defence experts, before admitting the evidence to be presented to the jury. Judge Pratt provided a comprehensive background on the scientific method of DNA profiling, before addressing the legal standard of admissibility for novel scientific evidence. He stated that the majority of jurisdictions who had faced similar issues adopted the *Frye* test and this remained the majority rule, but also

⁷⁰³ *United States of America v. Randolph Jacobetz*, 955 F.2d 786 (1992).

acknowledged the shortcomings and how the Federal Rules of Evidence and the Article VII rules addressed the shortcomings. He stated that:

“We likened the standard for admissibility of scientific evidence to that for other evidence, and we stated that evidence is admissible if the probativeness, materiality, and reliability of the evidence outweighs its tendency to mislead, prejudice, and confuse the jury.”⁷⁰⁴

Judge Pratt held that probativeness and materiality of most scientific evidence proffered to the jury are normally not in dispute and provided five factors that could affect a court’s determination of reliability which derive from the case of *United States v. Williams*.⁷⁰⁵ These included:

- potential rate of error;
- existence and maintenance of standards;
- care and concern with which a scientific technique has been employed, and whether it appears to lend itself to abuse;
- existence of an analogous relationship with other types of scientific techniques and results that are routinely admitted into evidence;
- presence of “fail-safe” characteristics or the likelihood that potential inaccuracies will rebound to the defendant’s benefit rather than his detriment.⁷⁰⁶

He used these reliability factors in conjunction to the Federal Rules of Evidence 403 to determine whether the probative value of proffered evidence substantially outweighed its danger to unfair prejudice. He also referred to the three-prong test in the *Castro* case, discussed above. In his final deliberation, Judge Pratt stated that although DNA evidence presented special challenges, it was not that special as to require new standards of admissibility, and in spite of its novelty, complexity, and confusing evidence, the jury must retain their fact finding function. The court must allow the jury to discharge its duties of weighing the evidence, making credibility determinations, and ultimately deciding the facts, rather than focus on admissibility or non-admissibility of scientific

⁷⁰⁴ *Jacobetz* [749].

⁷⁰⁵ *United States v. Williams*, 583 F.2d 1194, 1198 (2d Cir.1978), cert. denied, 439 U.S. 1117, 99 S.Ct. 1025, 59 L.Ed.2d 77 (1979).

⁷⁰⁶ *Williams* [1198-99].

evidence. He concluded that the district court properly exercised its discretion in admitting the DNA profiling evidence proffered by the government and affirmed the *Jacobetz* conviction. During the novel stage of DNA profiling, various courts used different approaches for the admissibility of DNA evidence during trials.⁷⁰⁷

6.5.4.3 The case of *M. Van D.* (Netherlands)

Across the Atlantic, the Netherlands was one of the pioneer countries in the use of DNA in criminal matters. In 1988, DNA was used for the first time in a criminal trial. In the case in question, DNA material was used to investigate whether a 24-year old, known as M. Van D., convicted of raping four women, had indeed been the perpetrator of these crimes in 1985.^{708,709} One victim recognised the face and voice of the perpetrator and the second, who was blindfolded, recognised his voice. Two possible semen samples were also collected from the crime scenes. The suspect's blood was obtained for blood grouping and phosphoglucomutase to determine whether an enzyme was

⁷⁰⁷ See *United States v. Jacobetz*, 747 F.Supp. 250 (D.Vt.1990). It is generally conceded that DNA profiling is relatively new and has been the subject of controversy in both the legal and scientific fields.[6] Several state courts, however, have admitted DNA evidence. *Andrews v. State*, 533 So.2d 841 (Fla. Dist. Ct. App. 1988) (finding DNA evidence admissible using a relevancy test); *Caldwell v. State*, 260 Ga. 278, 393 S.E.2d 436 (1990) (admitting DNA evidence but not population statistics); *Cobey v. State*, 80 Md.App. 31, 559 A.2d 391 (1989) (admitting DNA evidence using Frye test); *State v. Schwartz*, 447 N.W.2d 422 (Minn. 1989) (admitting DNA evidence if tests performed properly); *People v. Castro*, 144 Misc.2d 956, 545 N.Y.S.2d 985 (Sup. Ct. 1989) (using three step test to determine whether to admit DNA evidence); *People v. Wesley*, 140 Misc.2d 306, 533 N.Y.S.2d 643 (Albany County Ct. 1988) (admitting DNA evidence under the Frye test); *State v. Pennington*, 327 N.C. 89, 393 S.E.2d 847 (1990) (finding DNA evidence admissible); *State v. Ford*, S.C., 392 S.E.2d 781 (1990) (admitting DNA evidence and, because technique generally accepted, future Frye hearings unnecessary); *Glover v. State*, 787 S.W.2d 544 (Tex. Ct. App.) (admitting DNA evidence using the Frye test), review granted (1990); *Spencer v. Commonwealth*, 238 Va. 275, 384 S.E.2d 775 (1989) (using reliability test to find DNA evidence admissible) (case one), cert. denied, ___ U.S. ___, 110 S.Ct. 59*59 759, 107 L.Ed.2d 775 (1990); *Spencer v. Commonwealth*, 238 Va. 295, 384 S.E.2d 785 (1989) (admitting DNA evidence) (case two), cert. denied, ___ U.S. ___, 110 S.Ct. 1171, 107 L.Ed.2d 1073 (1990). Although DNA analysis has been used in forensics only recently, it has been used for several years in diagnostics. *Andrews*, 533 So.2d at 848-49; *Caldwell*, 260 Ga. at 286, 393 S.E.2d at 441; *Ford*, ___ S.C. at ___, 392 S.E.2d at 783. It has also been used in determining parentage. In re *Baby Girl S.*, 140 Misc.2d 299, 532 N.Y.S.2d 634 (Sur. Ct. 1988) (finding it unnecessary to have hearing on DNA evidence admissibility when state statute provided for admission of blood genetic marker tests).

⁷⁰⁸ Reformatorisch Dagblad "Verkrachter vrijuit na DNA-onderzoek: Hof accepteert nieuw bewijsmiddel" 1988-10-05. <https://www.digibron.nl/search/detail/012e936a2d2fb43917c44be3/verkrachter-vrijuit-na-dna-onderzoek> (Date of use: 1 November 2018).

⁷⁰⁹ Vervaele JAE *et al.* "The Dutch focus on DNA in the criminal justice system: net-widening of judicial data" 2012 *Revue Internationale de Droit Pénal* 83(3-4):459-480.

present in both the blood and semen sample found on scene. The likelihood of the test showed a blood group present in 40 % of the population, 8 % of the population based on the enzyme type, and only 1 % within males between 20 and 40 years of age. Although the evidence favoured the prosecution, the defence attorney in the case, Mr. C. Korvinus, requested that the samples be sent to England for DNA testing, as they were not geared to do it locally. The subsequent results, however, showed similarity between the two semen samples, but could not compare them to the blood sample of the suspect. The convicted person was acquitted from all charges in The Court of Amsterdam. A DNA investigation was thus carried out after a conviction.

The investigation was assumed to be based on article 195 of the Dutch Code of Criminal Procedure (CCP), which made it possible to physically investigate the accused individual's body. However, the Dutch Supreme Court decided in 1989, that this competence did not cover the possibility of a DNA investigation. As a result, legislation dealing with the use of DNA in criminal proceedings was formulated in 1994.⁷¹⁰ The first legislative package on DNA in criminal proceedings was introduced in order to meet the procedural legality principle under article 1 CCP, and thus to create sufficient possibilities to use DNA as an investigative and evidentiary tool in criminal proceedings.

In these early cases, legal professionals had limited knowledge of this novel scientific method and most arguments were based on the *Frye* rule to exclude the evidence from trials. The new DNA-based forensic analysis of crime scene samples was significantly more informative than the older serological methods used before. Within a decade of its introduction, DNA evidence successfully made it into the courtroom in all criminal and civil trials. It was used by both counsel to either prove guilt or innocence of individuals. Defence attorneys had to find new strategies to prohibit or challenge the value of the evidence other than the fact that it was a new scientific method. Due to the widespread use of DNA profiling in a larger science community, it was getting more difficult to challenge the reliability and validity of the method unless those legal professionals had a better understanding of the science behind the method. The challenges were far from over as certain aspects, such as the quality of the results, the basis for the derivation and interpretation of thereof,

⁷¹⁰ Staatsblad van het Koninkrijk der Nederlanden, Stb. 1993, 596, 2001.

were hardly addressed. There was also a need to work on the probability of finding a matching sample at random in a given population and challenges associated with that.⁷¹¹

6.6 External entities and events that influenced the credibility of DNA evidence

6.6.1 A quest for more DNA research in forensic science

With the revolutionary developments of DNA profiling, the United States National Research Council formed the Committee on DNA Technology in Forensic Science in 1989, to study this technique and its applications. The Committee issued its first report in 1992. The report resolved a number of questions, and several of its recommendations were widely adopted. The committee stated in the preface the following:

“DNA analysis promises to be the most important tool for human identification since Francis Galton developed the use of fingerprints for that purpose. We can confidently predict that, in the not-distant future, persons as closely related as brothers will be routinely distinguished, and DNA profiles will be as fully accepted as fingerprints now are. But that time has not yet arrived, and the winds of controversy have not been stilled. Hence this report. The technique for DNA profiling first appeared about 10 years ago, and the subject is still young. In the early days there was doubt, both as to the reproducibility and reliability of the methods and as to the appropriateness of simplistic calculations that took no account of possible subdivision of the population. Despite the potential power of the technique, there were serious reservations about its actual use”.⁷¹²

In the introduction of the 1992 report, the committee wrote:

“[T]he committee reviewed the scientific literature and the legal cases and commentary on DNA profiling, and it investigated the various criticisms that have been voiced about population data, statistics and laboratory error. Much has been learned since the last report. The technology for DNA profiling and the methods for estimating frequencies and related statistics have progressed to the point where the reliability and validity of properly collected and analyzed DNA data should not be in doubt. The new recommendations presented here should pave the way to more effective use of DNA evidence”.⁷¹³

⁷¹¹ McElfresh KC *et al.* “DNA-based Identifiy Testing in Forensic Science, Court admissibility of DNA data has survived five years of strong challenges” 1993 *Bioscience* 43(3):149-157.

⁷¹² National Research Council *The evaluation of forensic DNA evidence prepublication copy* (National Academic Press Washington DC 1996).

⁷¹³ NRC “Executive summary” 1996 ES-1.

The report made many recommendations for improvement. Some of the more important ones are mentioned below:

- Completion of adequate research into the properties of typing methods to determine the circumstances under which they yield reliable and valid results;
- Creation of a national committee on forensic DNA typing to evaluate scientific and technical issues arising in the development and refinement of DNA-typing technology;
- Studies of the relative frequencies of distinct DNA alleles in 15-20 relatively homogeneous sub-populations;
- A ceiling principle, using as a basis of calculation the highest allele frequency in any subgroup or 5 %, whichever is higher;
- A more conservative "interim ceiling principle" with a 10 % minimum until the ceiling principle can be implemented;
- Proficiency testing to measure error rates and to help interpret test results;
- Quality-assurance and quality-control programs;
- Mechanisms for accreditation of laboratories;
- Increased funding for research, education, and development;
- Judicial notice of the scientific underpinnings of DNA typing;
- Databases and records freely available to all parties;
- An end to occasional expert testimony that DNA typing is infallible and that the DNA genotypes detected by examining a small number of loci are unique.

After the report, the five key stages in the forensic DNA profiling process had to be better defined by the DNA community, namely, extraction of DNA from sample, quantification, amplification, detection, and interpretation. Each step required some level of development and validation as time progressed. Some of the recommendations mentioned generated controversy and criticism.⁷¹⁴

⁷¹⁴ Balazs I "Population genetics of 14 ethnic groups using phenotypic data from VNTR loci" 1993. In: Pena SDJ *et al.* *DNA fingerprinting: state of the science* (Basel, Switzerland: Birkhäuser Verlag) 193-210. Also, Devlin B *et al.* "Statistical evaluation of DNA fingerprinting: a critique of the NRC's report" 1993 *Science* 259:748-749, 837. Also, Devlin B *et al.* "Comments on the statistical aspects of the NRC's report on DNA typing" 1994 *J Forensic Sci* 39: 28-40. Also, Kaye DH "DNA evidence: probability, population genetics, and the courts" 1994 *Harvard J Law Technol* 7:101-

Much of that centered on the “interim ceiling principle”, a procedure intended to provide an estimate of a profile frequency that is highly conservative (i.e., favourable to the defendant) and independent of the racial origins of the DNA. The principle was criticised on the grounds of being arbitrary and unnecessarily conservative, and not taking population genetic theory into account, and also as being subject to misuse. Although most of the recommendations were remedied and implemented in many laboratories, the most contentious issues have involved statistics, population genetics, and possible laboratory errors in DNA profiling.

To evaluate progress made, in 1994 the National Research Council established a committee to update and clarify the 1992 report. The updated report was published in 1996⁷¹⁵ and the major issues addressed in the report were divided into three groups, each with specific questions:

- The accuracy of laboratory determinations. How reliable is genetic typing? What are the sources of error? How can errors be detected and corrected? Can their rates be determined? How can the incidence of errors be reduced? Should calculation of the probability that an uninvolved person has the same profile as the evidence DNA include an estimate of the laboratory error rate?
- The accuracy of calculations based on population-genetics theory and the available databases. How representative are the databases which originate from convenience samples rather than random samples? How is variability among the various groups in the US population best taken into account in estimating the population frequency of a DNA profile?
- Statistical assessments of similarities in DNA profiles. What quantities should be used to assess the forensic significance of a profile match between two samples? How accurate

172. Also, Morton NE *et al.* “Kinship bioassay on hypervariable loci in blacks and Caucasians” 1993 *Proc Natl Acad Sci USA* 90:1892-1896. Also Collins A and Morton NE “Likelihood ratios for DNA identification” 1994 *Proc Natl Acad Sci USA* 91:6007-6011.

⁷¹⁵ National Research Council (NRC) Report, Committee on DNA Forensic Science, “*The Evaluation of Forensic DNA Evidence*” National Academic Press Washington DC 1996.
<https://www.ncjrs.gov/pdffiles1/Digitization/166538NCJRS.pdf> (Date of use: 18 January 2020).

are these assessments? Are the calculations best presented as frequencies, probabilities, or likelihood ratios?⁷¹⁶

The more central question posed in the report was: “What information can a forensic scientist, population geneticist, or statistician provide to assist a judge or jury in drawing inferences from the findings of a match?”⁷¹⁷

The report provided a better description of the science behind DNA profiling, and had the data on the frequency of profiles in human populations. It also made recommendations on procedures to be used when providing statistical layouts useful in courtroom testimony.⁷¹⁸ These procedures were based on population genetics and statistics, and rendered the ceiling and interim ceiling principle redundant.

In the period that followed, researchers used the recommendations and continued to improve the DNA technique. This period was seen as the “golden research age” of DNA fingerprinting and formed two decades of engineering, implementation, and high-throughput application⁷¹⁹. Jeffreys’ original technology, now obsolete for forensic use, underwent important improvements in terms of the basic methodology, that is, from Southern blot to PCR, from radioactive to fluorescent labels, and from slab gels to capillary electrophoresis. As the technique became more sensitive, DNA profiling entered the forensic routine in laboratories around the world. However, what mattered in the *Pitchfork* case and what still matters today, is the process regarding the legal recognition of DNA identification results in legal proceedings.

A further challenge for crime laboratories, as the development of new data display required larger electronic storage space to keep data and for comparison purposes, was to increase electronic

⁷¹⁶ NRC Report *Introduction* 1996 [1-3].

⁷¹⁷ NRC Report *Executive Summary* 1996 [ES-1].

⁷¹⁸ NRC Report *Recommendation* 1996 [O-33].

⁷¹⁹ Jeffreys AJ *Foreword* *Fingerprint News* 1989 1:1. Dear Colleagues, [...] I hope that *Fingerprint News* will cover all aspects of hypervariable DNA and its application, including both multi-locus and single-locus systems, new methods for studying DNA polymorphisms, the population genetics of variable loci and the statistical analysis of fingerprint data, as well as providing useful technical tips for getting good DNA profiles [...]. May your bands be variable?

capacity. To prevent endless hours for searching older DNA profiles, laboratories required a solution to ease searching times. Researchers and information technologists were looking at ways of storing large quantities of data and effective search engines for matching.

6.6.2 DNA Databases

Initially, two requirements for the establishment of databases existed, namely: (1) the legal requirements governing the storage of a person's data on the database and, (2) the establishment of specified formats to store the data.

The mid-1990s saw the start of DNA databases, but this required legislation regulating where and whose DNA profiles could and should be kept for future comparisons. Legislators found themselves on unfamiliar grounds with the steady growth of DNA databases, which raised issues of inclusion and retention of profiles and doubts on the infringement of privacy, commensurability, and efficiency on personal data collections. Those advocating DNA databases claimed that the profiles of millions of past offenders could be stored and used in all types of crimes and that these profiles were no longer restricted to serious crimes. Due to that capability, databases were created within local crime laboratories and jurisdictions. After the introduction of amplification technology linked to STR, a sufficiently sensitive and robust system was available to create effective and efficient national and international DNA profiling systems.

The Federal Bureau of Investigation (FBI) began with a pilot software project Combined DNA Index System (CODIS), serving 14 state and local laboratories in 1990 already.⁷²⁰ The DNA Identification Act of 1994 formalised the FBI's authority to establish a National DNA Index System (NDIS) for law enforcement purposes. Today, over 190 public law enforcement laboratories participate in NDIS in the US and more than 90 law enforcement laboratories in over 50 countries use the CODIS software. CODIS is structured into separate indices, according to sample types: Convicted offender index, Arrestee index, Forensic index (for biological evidence collected from crime scenes), and indices for unidentified human remains and voluntary samples collected from

⁷²⁰ Federal Bureau of Investigation (FBI) "*Combined DNA Index System (CODIS)*".
<https://www.fbi.gov/services/laboratory/biometric-analysis/codis> (Date of use: 16 October 2018).

relatives of missing persons.⁷²¹ CODIS is also structured into three jurisdictional levels, the NDIS maintained by the FBI, State DNA Index Systems (SDIS) which are typically overseen by the state-level crime lab, and Local DNA Index Systems (LDIS) which have profiles from individual, local-level laboratories.

These developments were not limited to the United States only. In April 1995 the United Kingdom enacted comprehensive legislation for the first national DNA database, called National DNA Database (NDNAD), to be used by forensic scientists. The database would keep personal DNA profiles and crime scene evidence profiles. Other countries in Europe followed, some with more restrictions on whose information will be retained on the database and where will it be kept. In 1997, a DNA database was set up at the National Forensic Institute (NFI) in the Netherlands, containing DNA profiles. Although there was some discussion at the beginning, it was clear that the storage of DNA profiles would be the exclusive competence of the NFI under the guidance of the prosecutor. In other words, a DNA investigation (including sampling/profiling) would be a prosecutorial and not a police matter. The police authorities, even though they have judicial functions, were not allowed to set up their own DNA databases.⁷²² In 2009, the European Council recommended that all DNA profiling systems be standardised for international data-sharing, and all member states, including the United Kingdom, committed to adopt multiplexes covering the European Standard Set of *loci*, by November 2011.⁷²³ In 2015, Mapes *et al.*⁷²⁴ published a paper on DNA successes and the need for optimisation of the Offender DNA database, as there were only 3 % matches on serious crime cases and 1 % on high volume crime cases in the United Kingdom. By 1998, Austria and Germany successfully introduced DNA databases.⁷²⁵

⁷²¹ 42th United States Congress §14132, Title 34, Subtitle I, Chapter 121, Sub-chapter VIII / Part A / § 12592 “Index to facilitate law enforcement ex-change of DNA identification information”.

⁷²² Martin PD *et al.* “A brief history of the formation of DNA databases in forensic science within Europe” 2001 *Forensic Sci Int J* 119(2):225-31.

⁷²³ European Union Council “*Resolution on the exchange of DNA analysis results*” 2009-11-30 (OJ 2009 C 296/1).

⁷²⁴ Mapes AA *et al.* “DNA in the Criminal Justice System: The DNA Success Story in Perspective” 2015 *J Forensic Sci Jul* 60(4): 851-6.

⁷²⁵ Schneider PM “DNA databases for offender identification in Europe-the need for technical, legal and political harmonization”, in: *Proceedings of the 2nd European Symposium on Human Identification* 1998 Promega Corporation Madison WI USA 40–44.

South Africa's database was introduced in 1998 (DNA Criminal Intelligence Database [DCID]). In February 2009, the Department of Justice requested parliament for an amendment to the 1977 Criminal Procedure Act, making it mandatory that suspects or convicts have their DNA profiles taken to ascertain whether there is a match between profiles taken from the crime scene and the suspect's.⁷²⁶ The Criminal Law (Forensic Procedures) amendment Bill (B9B-2013)⁷²⁷ was enacted on 12th November 2013 and provides for the taking of specified bodily samples from certain categories of persons for the purposes of forensic DNA analysis. It also provides for the establishment, regulation, and maintenance of the National Forensic DNA Database.⁷²⁸ The DNA profiles in the DCID are generated by analysing an AmpFISTR Profiler Plus STR multiplex system of 9 different STR *loci* (D3S1358, vWA, FGA, D8S1179, D21S11, D18S51, D5S818, D13S317 and D7S820) plus Amelogenin for sex determination⁷²⁹.

Human rights groups continue to protest against these established DNA databases, and in one article, titled "DNA in the wrong hands", the author argues that such law is unconstitutional and contrary to South Africa's constitutional democracy.⁷³⁰ This article maintains that the database was put into the wrong hands when established within the South African Police Service.

In Australia, the National Criminal Investigation DNA Database (NCIDD) was established in June 2001 to facilitate intra-jurisdictional matching of DNA profiles, and inter-jurisdictional matching of profiles between participating jurisdictions, for law enforcement purposes. In February 2003, the Commonwealth established three DNA databases for law enforcement purposes.⁷³¹ Part 1D of

⁷²⁶ "Carte Blanche: Forensics" 2007-09-02 *M-Net*. Archived from the original on 2012-09-22. Seale Lebogang (2012-06-12) "Barring easy escape 2013-03-16 *The Star*.

⁷²⁷ The Criminal Law (Forensic Procedures) Amendment Act No. 37 of 2013 (the "DNA Act").

⁷²⁸ Republic of South Africa "Criminal Law: Forensic Procedures Amendment Bill" 2013. https://juta.co.za/media/filestore/2013/08/B9B_2013.pdf (Date of use: 16 October 2018).

⁷²⁹ Meintjes-van der Walt, L (2008). "An overview of the use of DNA evidence in South African criminal courts" 2008 *South African J Crim Justice* 21(1):22–62. Also, Hancock C "No need to question the validity of DNA evidence" 2013-11-20 *DNA Project*.

⁷³⁰ Naidoo P "In the Wrong Hands: A DNA Database in South Africa" 2013 Forensic Genetics Policy Initiatives. <http://dnapolicyinitiative.org/genewatch-forensic-dna/in-the-wrong-hands-a-dna-database-in-south-africa/> (Date of use: 16 October 2018).

⁷³¹ Australian Government "Australian Law Revision Commission" The Protection of Human Genetic Information in Australia (ALRC Report 96): 43. DNA Database Systems" 28 July 2010. <https://www.alrc.gov.au/publications/43-dna-database-systems/dna-database-systems> (Date of use: 16 October 2018).

the Crimes Act regulates the use, storage, disclosures, and removal of information held on the DNA database system.⁷³²

Besides DNA databases, other databases were also developed for the Y-chromosome haplotype and mitochondrial DNA (mtDNA). The largest forensic Y-chromosome haplotype database is the YHRD,⁷³³ updated and maintained by the Institute of Legal Medicine and Forensic Sciences in Berlin, Germany, with about 115,000 haplotypes sampled in 850 populations.⁷³⁴ In 2007, the most comprehensive forensic mtDNA database was EMPOP,⁷³⁵ updated and maintained by the Institute of Legal Medicine in Innsbruck, Austria, with about 33,000 haplotypes sampled in 63 countries.⁷³⁶

More than 235 institutes had actually submitted data to the YHRD and 105 to EMPOP, a clear demonstration of the level of networking activities between forensic science institutes globally. The additional intelligence information was potentially derivable from such large datasets and became obvious when a target DNA profile was searched against a collection of geographically annotated Y-chromosomal or mtDNA profiles. Because linearly inherited markers have a highly non-random geographical distribution, the targeted profile shared characteristic variants with geographical neighbors due to common ancestry.⁷³⁷ If law enforcement can obtain this information they are able to interrogate relatives of the suspected DNA profile discovered on the crime scene. The interrogation of relatives can be seen as harassment of innocent individuals who have no knowledge of the behavior of their relatives and can lead to an infringement of their right to privacy. The United States statute that protects these databases is the Health Insurance Portability and Accountability Act (HIPAA).⁷³⁸ The Privacy Rule states that genetic information is health information and therefore protected. This issue will be further discussed under the next section.

⁷³² Crimes Act 1914 (Cth) s 23YDAC.

⁷³³ Forensic Y chromosome haplotype database Promega <http://www.yhrd.org>. (Date of use: 16 October 2018).

⁷³⁴ Willuweit S and Roewer L "International Forensic Y Chromosome User Group. Y chromosome haplotype reference database (YHRD): update" 2007 *Forensic Sci Int Gen* 1:83–87.

⁷³⁵ Forensic mtDNA database <http://www.empop.org/>. (Date of use: 16 October 2018).

⁷³⁶ Parson W and Dür A "EMPOP - A forensic mtDNA database" 2007 *Forensic Sci Int Gen* 1:88–92.

⁷³⁷ Roewer L *et al.* "Signature of recent historical events in the European Y-chromosomal STR haplotype distribution" 2005 *Hum Gen* 116:279–291.

⁷³⁸ Code of Federal Rules (CFR), 45 C.F.R. § 160.103, 2000.

In 2014, Wallace *et al.* published a paper on Forensic DNA databases, titled “Ethical and Legal standards: A global review”.⁷³⁹ They relied on data from Forensic Genetics Policy Initiative⁷⁴⁰ to provide a summary on global trends and issues for debate on DNA profile databases. These include:

- The need for legislative provisions for the destruction of biological samples and deletion of innocent persons’ DNA profiles;
- Emerging best practice on scientific standards and standards for the use of DNA in courts; and
- Appropriate safeguards for DNA collection from suspects; restrictions on access, use and data sharing across borders; and data protection standards.

In 2017, DNA databases were prominent on federal and state level in the United States, as well as in some jurisdictions globally, who all collect DNA samples from individuals convicted of certain crimes.⁷⁴¹ Some databases even contain the DNA profiles of individuals arrested, but not convicted for smaller offenses.⁷⁴² In many of these jurisdictions, guidelines and policies determine steps to be taken when charges are dropped or the individual is acquitted from the crime, but in others individuals have to initiate the process.⁷⁴³ A universal DNA database was suggested by Dedrickson⁷⁴⁴ in 2017. It would contain uniform privacy policies currently held by entities, with three possible changes, to:

- include all individuals, not just those convicted or arrested for qualifying offenses;

⁷³⁹ Wallace HM *et al.* “Forensic DNA databases—Ethical and legal standards: A global review” 2014 *Egyptian J Forensic Sci* 4:57-63.

⁷⁴⁰ Forensic Genetics Policy Initiatives <http://dnapolicyinitiative.org/> (Date of use: 15 November 2018).

⁷⁴¹ DNA Resource, State DNA Database Laws Qualifying Offenses (As of Sept. 2011), <http://www.dnaresource.com/documents/statequalifyingoffenses2011.pdf>. (Date of use: 19 February 2019).

⁷⁴² Federal Bureau of Investigation, CODIS – NDIS Statistics. <https://www.fbi.gov/services/laboratory/biometric-analysis/codis/ndis-statistics> (Date of use: 19 February 2019).

⁷⁴³ National Institute of Justice DNA Sample Collection from Arrestees (Dec. 7, 2012) <https://www.nij.gov/topics/forensics/evidence/dna/pages/collection-from-arrestees.aspx>. (Date of use: 19 February 2019).

⁷⁴⁴ Dedrickson K “Universal DNA databases: a way to improve privacy?” 2017 *J Law and the Biosciences* 4(3):637–647.

- repeal profile expungement laws; and
- better integrate or combine existing databases.

Although it seemed far-fetched, Dedrickson asserts that a universal DNA database would pose a minimal invasion of privacy. Benefits would be a decrease in crime rates; the reversing and preventing of false convictions; an increase in the effectiveness and efficiency of international crime investigations and better protection of the larger society against criminal activities.

The standardisation of data captured on DNA databases, whether nationally or internationally, was not the only concern. With more vendors and suppliers of newly developed technology in the field of forensic DNA, a body was needed to standardise and affirm new scientific developments. In order to overcome some of the concerns, novel strategies were introduced, such as to reduce the number of punitive database hits by using mixture interpretation and review of original electropherograms, thus minimising the risk of adventitious hits and making database searching more practical for application in criminal investigations.⁷⁴⁵

Another recent development was the passing of the Rapid DNA Act of 2017⁷⁴⁶ in the United States, which allows DNA profiles generated outside accredited laboratories to be used to search CODIS. This will allow non-technical individuals, such as police officers, to take buccal swabs at the police interview room of arrestees and within 90 minutes a DNA profile will be generated and searched against CODIS. No mixture deconvolution needs to be performed from a single source reference sample.

6.6.3 *Familial DNA databases*

As time progressed, large datasets were gathered and stored and new mining procedures based on correlation became feasible. One correlation is that of “Familial DNA” database searching, based on near matches between a crime stain and a databased individual, which could be a near

⁷⁴⁵ Noël J *et al.* “Searching a DNA databank with complex mixtures from two individuals” 2009 *Forensic Sci Int: Gen Suppl Ser* 2:464–465.

⁷⁴⁶ 115th Congress, Public Law 115-50, 131 STAT. 1001, August 18, 2017.

relative of the true offender.⁷⁴⁷ Traditional DNA searches looked at exact matches to unknown crime scene DNA evidence, but may only be successful if the source of the questioned DNA is within the database.⁷⁴⁸ Familial DNA only requires the correlation with closely related family that might be in the database. However, at first it only worked with male profiles, as the analysis of similarities focused mainly on the Y chromosome (male-to-male Familial DNA search).

The first successful Familial search was conducted in United Kingdom in 2004 and led to the conviction of Craig Harman of manslaughter.⁷⁴⁹ Craig Harman was convicted because of partial matches from Harman's brother. By 2013, the UK already had 38 convictions based on the use of Familial DNA.⁷⁵⁰ The strategy was subsequently applied in some U.S. states, but not at federal level. After a defeat at the European Court of Human Rights in 2008, the U.K. database removed 1.1 million profiles of innocent people originally placed on the database in May 2013. As the public became more aware of the benefits and risks associated with larger DNA databases, a stronger outcry has been voiced towards with regard to possible ethical and privacy breaches by those who govern the DNA databases. Civil liberties advocates have criticised⁷⁵¹ these searches and claimed it violates the Fourth Amendment's protection against unreasonable searches.⁷⁵² Other criticism relates to the overrepresentation of racial and ethnic minorities in CODIS and the potential

⁷⁴⁷ Maguire CN *et al.* "Familial searching: A specialist forensic DNA profiling service utilising the National DNA Database® to identify unknown offenders via their relatives - The UK experience" 2013 *Forensic Sci Int Gen* 8:1-9.

⁷⁴⁸ Greely HT *et al.* "Family ties: The use of DNA offender databases to catch offenders' kin" 2006 *J Law Med & Ethics* 34(2):248-262.

⁷⁴⁹ Clough S "World first for police as relative's DNA traps lorry driver's killer" 2004-04-20 *The Telegraph*. <https://www.telegraph.co.uk/news/uknews/1459727/World-first-for-police-as-relatives-DNA-traps-lorry-drivers-killer.html> (Date of use: 16 October 2018).

⁷⁵⁰ National DNA Database (NDNAD) Strategy Board. *Annual Report 2012-13*. London: The Home Office.

⁷⁵¹ Haimes E "Social and ethical issues in the use of familial searching in forensic investigations: Insights from family and kinship studies" 2006 *The J Law Med & Ethics* 32(2):263-276. Also, Kaye DH "The genealogy detectives: A constitutional analysis of "familial searching" 2013 *Am Crim Law Rev* 51(1):109-16. Also, Kim J *et al.* "Policy implications for familial searching" 2011 *Invest Gen* 2(1):22. Also, Murphy E "Relative Doubt: Familial Searches of DNA Databases" 2010 *Michigan Law Rev* 109(3):291-348.

⁷⁵² Constitution of the United States of America 1789 (rev. 1992), Amendment IV. The right of the people to be secure in their persons, houses, papers, and effects, against unreasonable searches and seizures, shall not be violated, and no Warrants shall issue, but upon probable cause, supported by Oath or affirmation, and particularly describing the place to be searched, and the persons or things to be seized.

disparate impact of familial DNA on minorities.⁷⁵³ In the United States, some states (such as California) allow such searches only in the event of major violent crimes where the public faces safety risks and where all other investigative efforts returned without results, whereas other states (such as Maryland) has statutorily banned the use of familial DNA searching.⁷⁵⁴

In June 2017, Niedzwiecki, Sherrill and Field, in support of the National Institute of Justice (NIJ), performed a multi-phased, mixed methods study on Familial DNA policies and practices.⁷⁵⁵ They performed in-depth case studies on states performing Familial DNA searches related to procedures and policies, interagency collaboration, training, cost, concerns, and challenges. They concluded that the Familial DNA search methodology is still in its infancy stage and more research was needed to fully understand the impact of its use.

6.6.4 Standardisation of DNA analysis

DNA awareness escalated as the media started to follow high profile international trials, placing a burden on crime laboratories to follow international standards. Two bodies of interest evolved from the international standardisation for forensic DNA: the first was the 1988 establishment of the Technical Working Group on DNA Analysis Methods (TWGDAM),⁷⁵⁶ later changed to the Scientific Working Group on DNA Analysis Methods (SWGAM), and the second group was the 1992 establishment of the European Network of Forensic Science Institutes (ENFSI), with the first elected Board in 1995 in Rijswijk, Netherlands⁷⁵⁷.

⁷⁵³ Greely *Family ties* 2011. Also Grimm DJ “The demographics of genetic surveillance: Familial DNA testing and the Hispanic community” 2007 *Columbia Law Rev* 107(5):1164-1194. Also Mares B “A chip off the old block: Familial DNA searches and the African American community” 2011 *Law & Inequality* 29(2):395-424. Also, McCarthy M “Am I my brother’s keeper? Familial DNA searches in the twenty-first century” 2011 *Notre Dame Law Rev* 86(1):381-412.

⁷⁵⁴ Ram N “Fortuity and Forensic Familial Identification” 2011 *Stanford Law Rev* 63(4):751-812.

⁷⁵⁵ Niedzwiecki E et al. “*Understanding Familial DNA searching: Policies, Procedures, and Potential Impact, Summary Overview*” Office of Justice Programs, June 2017. <https://www.ncjrs.gov/pdffiles1/nij/grants/251043.pdf> (Date of use: 9 January 2020).

⁷⁵⁶ Scientific Working Group on DNA Analysis Methods (SWGAM). <https://www.swgam.org/about-us> (Date of use: 16 October 2018).

⁷⁵⁷ European Network of Forensic Science Institutes (ENFSI). <http://enfsi.eu/history/> (Date of use: 16 October 2016).

A 1990 report by the congressional Office of Technology Assessment in the United States concluded that DNA tests were both reliable and valid in the forensic context, but required a strict set of standards and quality control measures before they could be widely adopted.⁷⁵⁸ The 1992 report of the National Research Council (NRC) also concluded that: “No laboratory should let its results with a new DNA typing method be used in court, unless it has undergone. [...] proficiency testing via blind trials”.⁷⁵⁹ The 1996 report⁷⁶⁰ recommended new ways of interpreting DNA data by implementing a set of statistical calculations that take population structure into account and enhance the validity of the scientific method.

Without adopting any international standards in any laboratory, it would be a challenge to defend results. If a laboratory decides to use an international standard or parts thereof, it should be noted why and in what extent it will be used in its own written policies and procedures.

Similar to developments regarding seized drugs in the United States, on February 4, 2014 the National Institute of Standards and Technology (NIST) announced the formation of the Organization of Scientific Area Committees (OSAC). The OSAC scientific area committees (SACs) provide direction and coordination for the work performed by the OSAC discipline-specific subcommittees. The Biology/DNA Scientific Area Committee formed three subcommittees, namely Biological Methods, Biological Data Interpretation and Reporting, and Wildlife Forensics. The Biological Methods Subcommittee focuses on standards and guidelines related to molecular and biochemical methods used to analyse evidence and reference items. The Biological Data Interpretation and Reporting Subcommittee focuses on standards and guidelines related to scientifically valid methods of interpretation, statistical analysis, and reporting of biological results. Lastly, the Wildlife Forensics Subcommittee focuses on standards and guidelines related to

⁷⁵⁸ U.S. Congress, Office of Technology Assessment. 1990 “*Genetic Witness: Forensic Uses of DNA Tests*” OTA-BA-438. Washington, DC: U.S. Government Printing Office, NTIS order #PB90-259110.

⁷⁵⁹ National Research Council *DNA Technology in Forensic Science* (1992 Washington, DC: National Academy Press) 55.

⁷⁶⁰ National Research Council, Division on Earth and Life Studies *The Evaluation of Forensic DNA Evidence*. Commission on Life Sciences, Committee on DNA Forensic Science (National Academic Press 1996).

taxonomic identification, individualisation, and geographic origin of non-human biological evidence based on morphological and genetic analyses.

Due to the relationship between the SWGDAM and the FBI with regard to the FBI Director's Quality Assurance Standards (QAS) for DNA Laboratories, the NIST and the FBI agreed to keep the SWGDAM operational with the FBI at the time. The FBI was convinced that the business activities of the SWGDAM Committees were critical for the operation of CODIS and continued with funding the SWGDAM Committees to ensure not only that the QAS are revised in an efficient manner, but also that the National DNA Index System (NDIS) Procedures are timely and appropriate for the current or emerging technologies which are used by NDIS-participating laboratories nationwide. Emerging forensic technologies such as Rapid-DNA testing and Next Generation Sequencing (NGS) were quickly becoming a reality, so the FBI had to ensure (through the SWGDAM) that topics such as nomenclature and genetic privacy could be made fully compatible with the CODIS system. Once the OSAC had disseminated guidance for the review and approval of standards and guidelines through its Forensic Science Code of Practice, draft SWGDAM guideline documents⁷⁶¹ would be submitted for review and comment to the OSAC administration. All approved SWGDAM guidelines will be provided to the OSAC for inclusion in its Registry of Approved Standards or Guidelines, as appropriate. After the OSAC business structure had been formally memorialised, the SWGDAM reviewed its business process for drafting and approving guidelines which are captured in its Bylaws, and, to the extent possible, incorporated all elements of the review process designated for the OSACs. This included a public review period for all guidelines and proposed changes to the QAS, which SWGDAM had implemented and formally incorporated into its Bylaws.

Several of the members of the Biology/DNA SAC, Biological Methods subcommittee, and Biological Data Interpretation and Reporting subcommittee, are also regular participants in the SWGDAM, which creates opportunities for collaboration and interaction between SWGDAM and

⁷⁶¹ Scientific Working Group on DNA Analysis Methods (SWGDAM), at <https://www.swgdam.org/publications> (Date of use: 9 June 2019).

the OSAC DNA efforts. The OSAC working group (Biological methods) are sub-divided into six additional groups, each working with tasks associated with DNA evidence.⁷⁶²

- DNA Training task group
- Validation task group
- Contamination task group
- Serology and Y-STR task group
- Sequencing: Massively Parallel Sequencing/Next Generation Sequencing task group
- Familial Searching task group

Each group was tasked to develop standards within their respective topic areas.

The ENFSI working group also continued their efforts to maintain standardised protocols for DNA evidence (collection to interpretation) in forensic science laboratories.⁷⁶³

6.6.5 Cases demonstrating a legal challenge to DNA standardisation

The TWGDAM had many successes with publicised standards and guidelines becoming *de facto* standards by international laboratories. Courts became more aware of the required standards for a quality forensic DNA analysis program. In the case of *State v Schwartz* in 1989, the South African High Court recognised the TWGDAM guidelines as a standard for the reliability of the RFLP DNA testing.⁷⁶⁴

In 1997, DNA evidence and standards came under scrutiny in the U.S appellate case of *United States v. Anthony Mark Shea*.⁷⁶⁵ The defence argued that the DNA evidence must be excluded because the FBI's PCR tests produced an unacceptably high percentage of erroneous results,

⁷⁶² OSAC working group Biological methods. <https://www.nist.gov/topics/forensic-science/biological-methods-subcommittee> (Date of use: 23 July 2019).

⁷⁶³ European Network of Forensic Science Institutes (ENFSI). <http://enfsi.eu/documents/best-practice-manuals/> (Date of use: 23 July 2019).

⁷⁶⁴ *State v. Schwartz*, 447 N.W. 2d 422 (Minn. 1989).

⁷⁶⁵ *United States of America, v. Anthony Mark Shea*, United States District Court, D. New Hampshire, 957 F.Supp. 331 (1997).

even if evidence samples were properly handled and the tests were properly performed. They based the argument on the testimony of Dr. Donald Riley, who claimed that the testing protocols could have resulted in typing errors because the testing protocols specified incorrect amplification and typing temperatures. He also stated that this problem was significant with the amplification and typing of the DQ Alpha regions. Because the control probes for both DQ Alpha and Polymaker tests are intended to detect DQ Alpha alleles, he argued that the testing conducted by the FBI could have produced erroneous results on both tests.

Judge Barbadoro rejected Dr. Riley's testimony based on the lack of peer-reviewed conclusion to support his theory and the lack of describing his test methods in sufficient detail to permit a conclusion that the methods are scientifically valid. Secondly, Dr. Riley did not offer any scientific support for his theory that this methodological flaw could produce false positive signals at the control probes.⁷⁶⁶ Judge Barbadoro accepted the published validation studies the FBI used on PCR testing protocols.

Legal challenges arose elsewhere in the world. One such example was in South Africa in 2001 in the case of the *State v Maqhina*, where the admissibility of DNA evidence was in question. The court held that where an accused's guilt depends solely on the results of scientific analyses, it is important to have excellent record keeping of all testing processes and controlled measures applied to enable objective verification by any third party expert and trial courts. In this case, the court held that the state had failed to prove the objective reliability of results and pointed out several shortcomings:

- The forensic expert did not follow appropriate standard protocols;
- The expert failed to run certain duplicate tests, which, according to the defence expert, made it difficult to determine the reliability of the test;
- The laboratory was not an accredited standard testing and calibration entity.

⁷⁶⁶ *US v. Shea* [339].

After the *Maqhina* case, the forensic laboratory in South Africa subscribed to and adopted international quality control protocols, such as the SWGDAM standards.⁷⁶⁷

As the years passed, research in the field continued and new technology advances were introduced. Interpol continues to play an integral part in the establishment of literature reviews to capture 3-year interval discoveries and changes to allow laboratory managers to stay current on these new developments and standard protocols. During this time, a large number of papers were dedicated to standardisation and validation of steps applied in the analysis of DNA evidence.⁷⁶⁸

Testimonial mistakes by practitioners should be distinguished from procedural mistakes. One of the leading advocates for high ethical standards in forensic DNA analysis and testimony, Dr. Antonel Olckers, a distinguished professor and owner of DNAbiotec (Pty) Ltd⁷⁶⁹ in South Africa, published extensively on the misinterpretation and overstatement of DNA evidence,⁷⁷⁰ lack of understanding of DNA evidence by legal professionals,⁷⁷¹ and the need for a forensic science profession.⁷⁷² One of the articles highlights multiple cases where forensic experts testified on the value of the evidence and misinterpreted DNA data.⁷⁷³ Many of these misinterpretations were

⁷⁶⁷ De Wet S *et al.* "DNA profiling and the law in South Africa " 2011 *PER / PELJ* (14)4:171-351.

⁷⁶⁸ 15th International Forensic Science Symposium in Lyon. Researchers who conducted the literature overview discovered more than 3 600 papers related to Biological evidence and DNA on PubMed (1990 to June 2007) and EMBASE (1993 to June 2007) databases.

⁷⁶⁹ DNAbiotec (Pty) Ltd <http://www.dnabiotec.com/> (Date of use: 3 February 2019).

⁷⁷⁰ Olckers A "DNA evidence in South Africa: Lessons learned to date" 2013 *Forensic Sci Int Gen Suppl Series 4*:160-161.

⁷⁷¹ Van Der Merwe A *et al.* "Training of legal professionals in DNA evidence" 2013 *Forensic Sci Int Gen Suppl Series 4*: 85-86.

⁷⁷² Olckers A *et al.* "Forensic science in South Africa: Status of the profession" 2013 *Forensic Sci Int Gen Suppl Series 4*:146-147.

⁷⁷³ *State v Parker*, 2000 TT P121, L18, Use of invalidated methods for DNA evidence submitted to court: SvP; SvA, TT P121, L18. *State v Ackerman*, 2002 (SvA), The following was testified with regard to SOPs "[...] for each procedure we use there is a standard operating procedure." SvA, TT P54, L3. Contradictory testimony was however delivered under cross examination: "[...] according to our SOP cannot be done..", SvA, TT P116, L2. "[...] SOP says we are not allowed to do that..", SvA, TT P116, L15. *State vs. Rapagadie*, 2010 (SvR), "If you have a match on nine loci, you are also going to have a match on 15 loci", SvR, testimony transcript (TT), page (P) 25, "The reason why America went over to more loci is to get the differentiation power closer to 100%, not because they had matches of 9 loci", SvR, TT P69, L12. line (L) 12 and L14. When the expert was asked if she was aware of instances where 9 STR loci gave a match, and 15 did not, she replied: "we have [...] 'never ever seen that in our country". SvR, TT P68, L16. The fact that this expert has not seen it is because the lab has not looked for it (personal communication), yet the court is brought under the impression that the phenomenon does not exist in South Africa. *State*

associated with DNA mixtures and will be addressed later in this chapter. Additional funding for research and development was needed to address issues surrounding procedural mistakes and to improve training of scientists and legal professionals.

6.6.6 External funding for research and development in forensic DNA

In 2005, DNA technological development received a huge boost in the United States when President George W. Bush allocated \$1 billion dollars over 5 years to improve the use of DNA in the criminal justice system. The money was allocated to improve training and research to ensure DNA technology will grow to its full potential in solving crime, protect the innocent, and identify missing persons.⁷⁷⁴ With all these accomplishments in DNA development, the importance of forensic DNA discipline was identified in the U.S. Senate report in 2005, which states that:

“While a great deal of analysis exists of the requirements in the discipline of DNA, there exists little to no analysis of the remaining needs of the community outside of the area of DNA. Therefore . . . the Committee directs the Attorney General to provide [funds] to the National Academy of Sciences to create an independent Forensic Science Committee.”⁷⁷⁵

With the allocated funding researchers were able to improve and validate aspects within the discipline.⁷⁷⁶ A summary of all the research developments can be gleaned from the Interpol report:

vs. *Mlanga*, 2013 (SvM), Asked if each person, based on 9 loci, has a unique profile the analyst testified “That’s correct”, SvM, TT P278, L12. Asked if a 15 STR profile is more reliable than a 9 loci STR profile, she answered “[...] it is more clear and [...] is better, but not more reliable”, SvM, TT P299, L5. Asked regarding the strength of a 15 loci STR vs a 9 STR profile, the answer was “It can make the results even stronger”, SvM, TT P279, L4. Only the version in favor of the prosecution was stated. “I have years of experience and I still have the ‘guts’ to interpret certain things”, e.g. the 30 allele. SvM, TT P289, L24.

⁷⁷⁴ Office of Justice Programs “The President’s DNA Initiative: Helping to Solve Crimes by *Sarah v. Hart*” DOJ September 2004 Volume 52 Number 5:34.

⁷⁷⁵ US Senate Report 2005 S Rep No 109-88: 46.

⁷⁷⁶ 15th International Forensic Science Symposium in Lyon. Researchers who conducted the literature overview discovered more than 3 600 papers related to Biological evidence and DNA on PubMed (1990 to June 2007) and EMBASE (1993 to June 2007) databases.

- STRs and Supporting Technologies
- MiniSTRs
- Y-STRs
- Mitochondrial DNA (mtDNA)
- Single Nucleotide Polymorphisms (SNPs)
- Automated DNA Extraction of Biological Evidence
- Low Copy Number and Sensitive DNA Detection
- Software Assistance for DNA Analysis and Interpretation of STR DNA Evidence

All the evaluations and validations studies supported the progress made within the forensic DNA discipline. International working groups were optimistic of the progress, but acknowledged that more work was required to move towards smaller error rates. The 15th International Forensic Science Symposium report provides a comprehensive overview of the progress made in this regard.⁷⁷⁷

6.6.7 The National Academy of Sciences (NAS) Report on Forensic Science

The 2009 NAS report⁷⁷⁸ strengthened DNA technology advances with its contribution on the successful prosecution and conviction of criminals, as well as the exoneration of innocent persons. The NAS committee stated that nuclear DNA methodology has rigorously shown to have the capacity to consistently demonstrate a connection between evidence found on crime scenes and a specific individual or source, which is done with a high degree of scientific certainty. However, the committee acknowledged that analytical-based disciplines hold a notable advantage over disciplines relying on expert interpretation, such as fingerprints and firearms. At the time of the report, DNA analysis of single-source and simple mixture samples included excellent examples of objective methods whose foundational validity had been properly established.⁷⁷⁹ The report found

⁷⁷⁷ 15th International Forensic Science Symposium in Lyon, France. 23-26 October 2007.
<https://strbase.nist.gov/tools/IFSS07-BioReview.pdf> (Date of visit: 12 January 2020).

⁷⁷⁸ NAS Report 2009.

⁷⁷⁹ NAS Report 2009 “Forensic DNA analysis belongs to two parent disciplines—metrology and human molecular genetics—and has benefited from the extensive application of DNA technology in biomedical research and medical application”.

that interpretation of a single individual's DNA profile involved little to no human judgment and when laboratory protocols are followed as defined, errors were limited.⁷⁸⁰ The probability that two DNA profiles from different sources would have the same DNA profile (the random match probability) can easily be calculated based on the empirically measured frequency of each allele and established principles of population genetics.⁷⁸¹ It is, however, a little bit more complicated but still achievable when simple mixtures are analysed. Many assault and sexual assault cases will involve two individuals where one is known. More than 30 years' methods have been used to generate DNA profiles from the two sources by extracting DNA from sperm cells versus vaginal epithelial cells. When one profile is known, it can be subtracted from the set of alleles identified in the mixture before interpretation as a single source contributor.⁷⁸² Validation studies are thoroughly performed for accuracy, precision, and reproducibility of procedures followed during analysis of single and simple mixtures.⁷⁸³ The process for calculating the random match probability (that is, the probability of a match occurring by chance) is based on well-established principles of population

⁷⁸⁰ The examiner reviews the electropherogram to determine whether each of the peaks is a true allelic peak or an artifact (e.g., background noise in the form of stutter, spikes, and other phenomena) and to determine whether more than one individual could have contributed to the profile. In rare cases, an individual may have two fragments at a locus due to rare copy-number variation in the human genome.

⁷⁸¹ Random match probabilities can also be expressed in terms of a likelihood ratio (LR), which is the ratio of (1) the probability of observing the DNA profile if the individual in question is the source of the DNA sample and (2) the probability of observing the DNA profile if the individual in question is not the source of the DNA sample. In the situation of a single-source sample, the LR should be simply the reciprocal of the random match probability (because the first probability in the LR is 1 and the second probability is the random match probability).

⁷⁸² In many cases, DNA will be present in the mixture in sufficiently different quantities so that the peak heights in the electropherogram from the two sources will be distinct, allowing the examiner to more readily separate out the sources.

⁷⁸³ Budowle B *et al.* "Validation studies of the CTT STR multiplex system" 1997 *J Forensic Sci* 42(4):701-707. Also, Kimpton CP *et al.* "Validation of highly discriminating multiplex short tandem repeat amplification systems for individual identification" 1996 *Electrophoresis* 17(8):1283-93. Also, Lyg JE *et al.* "The validation of short tandem repeat (STR) loci for use in forensic casework" 1994 *Int J Legal Med* 107(2):77-89. Also, Fregeau CJ *et al.* "Validation of highly polymorphic fluorescent multiplex short tandem repeat systems using two generations of DNA sequencers" 1999 *J Forensic Sci* 44(1):133-166. For example, a 2001 study that compared the performance characteristics of several commercially available STR testing kits tested the consistency and reproducibility of results using previously typed case samples, environmentally insulted samples, and body fluid samples deposited on various substrates. The study found that all of the kits could be used to amplify and type STR loci successfully and that the procedures used for each of the kits were robust and valid. No evidence of false positive or false negative results and no substantial evidence of preferential amplification within a locus were found for any of the testing kits. See, Moretti TR *et al.* "Validation of Short Tandem Repeats (STRs) for forensic usage: performance testing of fluorescent multiplex STR systems and analysis of authentic and simulated forensic samples" 2001 *J Forensic Sci* 46(3):647-660.

genetics and statistics.^{784, 785} One of the shortcomings mentioned in the NAS report was the lack of sufficient DNA proficiency tests in crime laboratories.

Over time, defence experts have started to scrutinise the laboratory reports more carefully, and did not simply accept DNA reports without checking whether the actual test results fully support the conclusions. Despite the fact that little human judgment is required in the process, it is not infallible in practice. Although the probability that two samples from different sources may have the same DNA profile is tiny, the chance of human error is much higher. Such errors may come from sample mix-ups, contamination, incorrect interpretation, and errors in reporting.⁷⁸⁶ To minimise human errors, the FBI required, as a condition of participating in NDIS, that laboratories follow quality

⁷⁸⁴ The initial population data generated by FBI included data for 6 ethnic populations with database sizes of 200 individuals. See: Budowle B *et al.* "Population data on the thirteen CODIS core short tandem repeat loci in African Americans, U.S. Caucasians, Hispanics, Bahamians, Jamaicans, and Trinidadians" 1999 *J Forensic Sci* 44(6):1277-1286. Also, Budowle B *et al.* "CODIS STR loci data from 41 sample populations" 2015 *J Forensic Sci* 46(3):453-89. Errors in the original database were reported in July 2015 (Moretti TR *et al.* "Erratum" 2015 *J Forensic Sci* 60(4):1114-1116 - the impact of these discrepancies on profile probability calculations were assessed (and found to be less than a factor of 2 in a full profile), and the allele frequency estimates were amended accordingly. At the same time as amending the original datasets, the FBI Laboratory also published expanded datasets in which the original samples were retyped for additional loci. In addition, the population samples that were originally studied at other laboratories were typed for additional loci, so the full dataset includes 9 populations. These "expanded" datasets are in use at the FBI Laboratory and can be found at www.fbi.gov/about-us/lab/biometric-analysis/codis/expanded-fbi-str-final-6-16-15.pdf. More precisely, the frequency at each locus is calculated first. If the locus has two copies of the same allele with frequency p , the frequency is calculated as p^2 . If the locus has two different alleles with respective frequencies p and q , the frequency is calculated as $2pq$. The frequency of the overall pattern is calculated by multiplying together the values for the individual loci. The random match probability will be higher for close relatives. For identical twins, the DNA profiles are expected to match perfectly. For first degree relatives, the random match probability may be on the order of 1 in 100,000 when examining the 13 CODIS core STR loci. See: Butler JM "The future of forensic DNA analysis" 2015 *Phil Trans Royal Soc B* 370:1674.

⁷⁸⁵ Clayton TM *et al.* "Analysis and interpretation of mixed forensic stains using DNA STR profiling" 1998 *Forensic Sci Int* 91(1):55-70.

⁷⁸⁶ Krimsky S and Simoncelli T *Genetic Justice: DNA Data Banks, Criminal Investigations, and Civil Liberties* (Columbia University Press 2011). Perhaps the most spectacular human error to date involved the German government's investigation of the "Phantom of Heilbronn," a woman whose DNA appeared at the scenes of more than 40 crimes in three countries, including 6 murders, several muggings and dozens of break-ins over the course of more than a decade. After an effort that included analyzing DNA samples from more than 3,000 women from four countries and that cost \$18 million, authorities discovered that the woman of interest was a worker in the Austrian factory that fabricated the swabs used in DNA collection. The woman had inadvertently contaminated a large number of swabs with her own DNA, which was thus found in many DNA tests.

assurance standards as prescribed by the FBI.⁷⁸⁷ The QAS also required semi-annual proficiency testing of all DNA analysts that perform DNA testing for criminal cases, even before the NAS report. The results of the tests do not have to be published, but the laboratory had to retain the results of the tests, any discrepancies or errors made, and corrective actions taken.⁷⁸⁸ In this regard, Kloosterman *et al.*⁷⁸⁹ in 2014 and Butler in 2015 reported on DNA error rates in forensic DNA analysis. Thomson *et al.*⁷⁹⁰ listed a number of factors that may affect the conclusion or interpretation of results (such as mixtures, degradation, allelic dropout, spikes, blobs and other false peaks). These factors can introduce ambiguity into STR evidence, leaving the results open to alternative interpretations. This became a larger point of concern for the DNA community.

However, when technology improvement moves too fast, low funded laboratories and practitioners working in those laboratories may fall behind, which may lead to other forms of mistakes.

6.6.8 President's Council of Advisors on Science and Technology (PCAST) report

In the 2016, the PCAST report acknowledged the DNA analysis of single source and simple mixture samples, including excellent examples of objective methods whose foundational validity had been established. According to the PCAST committee, the foundation of DNA has been established from two parent disciplines, namely metrology and human molecular genetics, as well as the utilisation of technology in biochemical research and medical applications. The number of specific *loci* practices for entry into CODIS used by crime laboratories at the time of the PCAST evaluation was 13, which has since increased to 20 by the FBI, and therefore increasing the probabilistic weight in testimony. Although the committee applauded the validity and reliability of the methods applied in DNA casework (single source and simple mixtures), they emphasised that

⁷⁸⁷ FBI "Quality assurance standards for forensic DNA testing laboratories" 2011. <https://www.fbi.gov/file-repository/summary-of-new-revisions-to-qas-for-forensic-dna-testing-labs.pdf/view>. (Date of use: 3 March 2020).

⁷⁸⁸ FBI *Quality Assurance* Sections 12, 13, and 14.

⁷⁸⁹ Kloosterman A *et al.* "Error rates in forensic DNA analysis: Definition, numbers, impact and communication" 2014 *Forensic Sci Int Gen* 12:77-85. Also, Butler JM "DNA Error Rates" 2015 *presentation at the International Forensics Symposium, Washington, D.C.* www.cstl.nist.gov/strbase/pub_pres/Butler-ErrorManagement-DNA-Error.pdf. (Date of use: 8 December 2018).

⁷⁹⁰ Thompson WC *et al.* "Evaluation of forensic DNA evidence: essential elements of a competent defense review (part 1)" April 2003 *The Champion* 27(3):16-25.

errors can still occur in sample mix-ups, contamination, incorrect interpretation, and errors in reporting.⁷⁹¹ To limit human error, laboratories were required to follow the FBI's Quality Assurance Standards (QAS).⁷⁹² The report acknowledged the paper by Kloosterman *et al.*⁷⁹³ and presentation by Butler⁷⁹⁴ on error rates encountered in casework, categorised by type, source, and impact. One of the reasons mentioned for the transparency and cultural change in the Netherlands was the use of an inquisitorial approach to method of criminal justice, whereas the United States laboratories do not report quality issues in the adversarial system, but rather explain them in court. The report also re-emphasised the need for improved proficiency testing.

Most of the developments relating to complex mixtures in the PCAST report will be addressed in paragraph 6.7 of this chapter. A number of research papers have since been published to address the concerns mentioned,⁷⁹⁵ while other studies have evaluated the differences between interpretation models.⁷⁹⁶ The committee also recognised two software programs (STRmix™ and TrueAllele®) and validation studies performed on them to determine reliability within certain ranges.^{797,798} The committee called on practitioners for more scientific publications on this matter,

⁷⁹¹ Krimsky Genetic Justice 2011.

⁷⁹² FBI "Quality assurance standards for forensic DNA testing laboratories" 2011. www.fbi.gov/about-us/lab/biometric-analysis/codis/qas-standards-for-forensic-dna-testing-laboratories-effective-9-1-2011. (Date of use: 8 December 2018).

⁷⁹³ Kloosterman "Error rates" 2014.

⁷⁹⁴ Butler JM "DNA Error Rates" 2015 presentation at the International Forensics Symposium.

⁷⁹⁵ Perlin MW *et al.* "TrueAllele genotype identification on DNA mixtures containing up to five unknown contributors" 2015 *J Forensic Sci* 60(4):857-868. Also, Greenspoon SA *et al.* "Establishing the limits of TrueAllele® Casework: A validation study" 2015 *J Forensic Sci* 60(5):1263-1276. Also, Bright JA *et al.* "Developmental validation of STRmix™, expert software for the interpretation of forensic DNA profiles." 2016 *Forensic Sci Int Gen* 23:226-39. Also, Bright JA *et al.* "Searching mixed DNA profiles directly against profile databases" 2014 *Forensic Sci Int Gen* 9:102-110. Also, Taylor D *et al.* "Testing likelihood ratios produced from complex DNA profiles" 2015 *Forensic Sci Int Gen* 16:165-171. Also, Taylor D and Buckleton JS "Do low template DNA profiles have useful quantitative data?" 2015 *Forensic Sci Int Gen* 16:13-16.

⁷⁹⁶ Bille TW *et al.* "Comparison of the performance of different models for the interpretation of low level mixed DNA profiles" 2014 *Electrophoresis* 35:3125-3133.

⁷⁹⁷ Taylor *Testing likelihood ratios* 2015. Also, Bright Developmental validation 2016. Also, Bright JA *et al.* "Searching mixed DNA profiles directly against profile databases" 2014 *Forensic Sci Int Gen* 9:102-110. Also, Bieber FR *et al.* "Evaluation of forensic DNA mixture evidence: protocol for evaluation, interpretation, and statistical calculations using the combined probability of inclusion." BMC Genetics. <https://bmcbgenet.biomedcentral.com/articles/10.1186/s12863-016-0429-7> (Date of use: 14 December 2018).

⁷⁹⁸ Greenspoon *Establishing the limits* 2015. Also, Perlin *TrueAllele genotype identification* 2015 Also, Taylor D "Using continuous DNA interpretation methods to revisit likelihood ratio behavior" 2014

with high quality validation studies, to establish the range of reliability of methods used in complex DNA mixtures. The committee was of the view that the data already exists in crime laboratories and could be captured in publications.

The PCAST report received criticism from various role players, one of which was that of Budowle,⁷⁹⁹ who demonstrated that the PCAST Report was not scientifically sound; was not based on data; not well-documented; that it misapplied statistics; was full of inconsistencies, and did not provide helpful guidance to obtain valid results in forensic analyses. Another scientist of interest who challenged the findings made by the PCAST committee, was Buckleton,^{800,801} a well-known forensic scientist and DNA researcher at The Institute of Environmental Science and Research (ESR), in New Zealand. Buckleton alerted the PCAST committee to studies published with mixed DNA profiles to levels beyond the complexity and contribution levels suggested by PCAST. He also accused PCAST of only using data from peer reviewed literature and disqualifying well established data from real casework samples and for not using papers published by vendors, although they mentioned such studies in the latent fingerprint section of the report. The committee of PCAST also called for ideas for the future of DNA technology in their report, which will be discussed under the future aspects of DNA evidence section in this chapter.

Forensic Sci Int Gen 11:144-153. Also, Taylor *Testing likelihood ratios* 2015. Also, Taylor *DNA profiles* 2015. Also, Bright *Developmental validation* 2016.

⁷⁹⁹ UNT Center for Human Identification, June 17, 2017.

<https://workspace.forensicosac.org/higherlogic/ws/public/download/10132/170617-Budowle%27.pdf> (Date of use: 3 December 2018).

⁸⁰⁰ John Buckleton comments to PCAST. <https://johnbuckleton.wordpress.com/pcast/> (Date of use: 3 December 2018).

⁸⁰¹ DNA Labs International 7 September 2016. https://johnbuckleton.files.wordpress.com/2016/09/strmix-letter-for-pcast_dli_2016-dna-labs.pdf (Date of use: 3 December 2018).

6.7 DNA Mixtures

DNA analysis and profiles are not always adequately understood by both forensic experts and even less by the legal fraternity. The perception that DNA evidence is infallible obscures many potential problems raised by the methodology and interpretation of such evidence.⁸⁰² For example, an extensive inter-laboratory research study conducted by Dr. John Butler *et al.*⁸⁰³ of the National Institute of Standards and Technology (NIST) in 2005 discovered that even when trained DNA analysts were interpreting similar data, different conclusions and different statistical results were reported. Laboratories who participated in the study showed a difference of one order of magnitude in their statistical conclusions (ranging from 10^5 to 10^{15}) based on which alleles were deduced and reported.

The first approach to the application of DNA evidence to criminal cases involved calculating the percentage of the population excluded or included based on a DNA profile, which failed to consider the interactions between the amount of alleles and contributors based on the numerical evidence provided in mixed DNA stains.⁸⁰⁴ DNA mixtures most commonly consist of an unknown DNA profile and another known DNA profile, most commonly from the victim. As the number of contributors increase, the discriminatory power decrease.⁸⁰⁵ Although most forensic DNA mixtures are derived from blood and semen samples, hair, saliva, fingernails, and buccal cells should also be tested. The largest portion of DNA mixture interpretation problems are associated with sexual assault cases, which involve more than one male contributor profile being present in the sample. Samples may comprise a complex mixture of numerous unique and overlapping major and minor components; the peak heights may differ considerably; the differences in the amount and state of preservation of the DNA from each source may vary; and the “stutter peaks” that surround alleles

⁸⁰² Murphy E "The art in the science of DNA: A layperson's guide to the subjectivity inherent in forensic DNA typing" 2008 *Emory Law J* 58: 490.

⁸⁰³ Butler JM *et al.* "NIST inter-laboratory studies involving DNA mixtures (MIX05 and MIX13): Variation observed and lessons learned" 2018 *Forensic Sci Int Gen* 37:81-94.
[https://www.fsigenetics.com/article/S1872-4973\(18\)30248-5/fulltext](https://www.fsigenetics.com/article/S1872-4973(18)30248-5/fulltext) (Date of use: 3 December 2018).

⁸⁰⁴ Weir BS *et al.* "Interpreting DNA mixtures" 1997 *J Forensic Sci* 42(2):213-222.

⁸⁰⁵ Chung YK and Fung WK "Identifying contributors of two-person DNA mixtures by familial database search" 2013 *Int J Legal Med* 127:25–33.

can obscure alleles that are present from different individuals who must be identified for accurate analysis. This might lead to subjective interpretation in crime laboratories globally.⁸⁰⁶

In low quantity, DNA contributions are subject to stochastic effects (e.g., allele dropout, i.e. missing alleles) and allele drop-in (i.e. spurious alleles), and greater heterozygous (i.e. peak height variance). According to Buckleton *et al.*⁸⁰⁷ and Coble *et al.*,⁸⁰⁸ it is often not possible to distinguish with certainty which alleles are present in the mixture or the amount of contributors to the mixture, let alone to accurately infer the DNA profile of each individual. Frequency based statistics such as the probability of exclusion (PE) or the random match probability (RMP) cannot be used to evaluate the strength of the DNA evidence, because these probabilities do not account for the stochastic phenomena that create uncertainty about the composition of the sample. Probability values decrease by millions compared to those encountered in matches to single source DNA profiles. It is therefore critical that calculations are done properly of the statistical weight of the evidence presented in court. Cases from the past showed shortcomings in the subjective interpretation of DNA mixtures.

The weight of the evidence is given through the presentation of numerical statistics, which need to be explained in words for judges and juries to understand. The adopted methods by which crime laboratory reports weight the DNA evidence for the court is by presenting a Likelihood Ratio (LR) or the Combined Probability of Inclusion (CPI), also referred to as Random Man Not Excluded (RMNE), and random match probability. LR compares the probability of observing the evidence under two alternative hypotheses,⁸⁰⁹

$$LR = \frac{\Pr(E|H_p, n_p)}{\Pr(E|H_d, n_d)}$$

⁸⁰⁶ Butler "The future of forensic" DNA 2015.

⁸⁰⁷ Buckleton JS *et al.* "Towards understanding the effect of uncertainty in the number of contributors to DNA stains" 2007 *Forensic Sci Int Gen* 1(1):20-28.

⁸⁰⁸ Coble MD *et al.* "Uncertainty in the number of contributors in the proposed new CODIS set" 2015 *Forensic Sci Int Gen* 19:207-211.

⁸⁰⁹ Gill P *et al.* "DNA commission of the International Society of Forensic Genetics: Recommendations on the interpretation of mixtures" 2006 *Forensic Sci Int* 160(2):90-101.

where E is the evidence in the form of the electropherogram (epg); H_p and H_d are the hypotheses specified by the prosecution and the defence respectively; and n_p and n_d are the number of contributors specified by the prosecution and the defence respectively. The evidence shows support for the prosecution's hypotheses if $LR > 1$, while if $LR < 1$ the defence's hypothesis is supported. The early software models, although suitable for single DNA profiles, received justifiable criticism by some.^{810,811,812} However, later developments of new software in the late 2000s solved a large number of issues associated with DNA mixture interpretation, for example GeneMapper® and TrueAllele®.⁸¹³ Even with this new software, research moved slowly because of barriers such as the lack of validation, fear of complexity in its use, realistic implications of using "black box" technology, and the costs. By utilising quantitative information as much as possible within a DNA profile, more parameters can be incorporated and can contribute to an increased complex model, with underlying mathematics that are difficult to be explained by the average DNA scientist. Laboratory managers normally look for comprehensive models within reach of average DNA forensic scientists, supported by training and skills development. GeneMapper® uses two quantitative assessment parameters: M_x and heterozygous balance to calculate the intensity of DNA evidence mixtures using the LR method.⁸¹⁴ Too many factors affect the reliability when using this software, such as stutter bands, shared alleles, allelic loss, low-copy DNA and contamination. TrueAllele® was based on a probability profiling method using a mathematical model containing validation and quantitative probability.⁸¹⁵ The software could distinguish between three individuals

⁸¹⁰ Buckleton JS and Gill P "Further Comment on "Low copy number typing has yet to achieve "general acceptance" by Budowle B *et al.* 2009 *Forensic Sci Int Gen Suppl Series* 2:551–552.

⁸¹¹ Budowle B, Chakraborty R, van Daal A, Author's response to Gill P *et al.* "Mixture interpretation: defining the relevant features for guidelines for the assessment of mixed DNA profiles in forensic casework" 2010 *J Forensic Sci* 55(1):265–268.

⁸¹² Budowle B, van Daal A "Reply to Comments by Buckleton and Gill on "Low copy number typing has yet to achieve 'general acceptance'" by Budowle, B., *et al.* 2009 *Forensic Sci Int Gen Suppl Series* 2:551–552.

⁸¹³ Perlin MW *et al.* "Validating TrueAllele® DNA Mixture Interpretation" November 2011 *J Forensic Sci* 56(6):1430-1447. Also: Balding DJ and Buckleton J "Interpreting low template DNA profiles" December 2009 *Forensic Sci Int Gen* (4)1:1-10. Also: Lohmeuller KE and Rudin N "Calculating the Weight of Evidence in Low-Template Forensic DNA Casework" 2012 *J Forensic Sci* 58(1):243-249.

⁸¹⁴ Hansson O and Gill P "Evaluation of GeneMapper®ID-X Mixture Analysis tool" 2011 *Forensic Sci Int Gen Suppl Series* 3:11–12.

⁸¹⁵ Perlin "Validating TrueAllele® DNA mixture" 2011.

in a DNA mixture, but low signals remained a problem. There is also no threshold for an inclusion log (LR) when suspects could not be excluded as a source of the DNA mixture.

A DNA commission of the International Society of Forensic Genetics (ISFG) convened at the 21st congress of the International Society for Forensic Genetics, held between 13 and 17 September 2005 in the Azores, Portugal. The purpose of the commission was to agree on guidelines to highlight best practice that can be globally applied to assist with mixture interpretation. In addition, the commission was tasked to provide guidance on low copy number (LCN) reporting.⁸¹⁶ The publication resulted in developments in forensic techniques, mathematical models and software for improving mixture analyses and interpretation. Significant improvements were seen in sensitivity for trace samples in DNA mixtures.⁸¹⁷ The commission also provided guidelines to standardise the optimal practices for examining DNA mixtures and low copy number (LCN) reporting and was employed across the globe.⁸¹⁸

Soon thereafter, the Biology Specialist Advisory Group (BSAG) of the Australian and New Zealand forensic science community responded with publications to improve laboratory quality on DNA mixtures.⁸¹⁹ They focused on laboratory quality, and on the application of optimal techniques by research laboratories, even where it was not recommended by judicial systems. According to BSAG, LR was the preferred approach for the interpretation of mixed DNA samples, whereas the RMNE approach should be restricted to explicit DNA profiles. In spite of all the various approaches and applications, subjective decisions still played a role when interpreting DNA mixture electropherograms.

With subjective decision making added into the analytical process, error rates would be expected to increase and studies had to be conducted to determine how much influence occurred in

⁸¹⁶ Gill “DNA Commission” 2006.

⁸¹⁷ Morling N *et al.* “Interpretation of DNA mixtures - European consensus on principles” 2007 *Forensic Sci Int Gen* 1:291–292.

⁸¹⁸ Gill P *et al.* “Technical UK DNA working group. National recommendations of the Technical UK DNA working group on mixture interpretation for the NDNAD and for court going purposes” 2008 *Forensic Sci Int Gen* 2:76–82.

⁸¹⁹ Stringer P *et al.* “Interpretation of DNA mixtures - Australian and New Zealand consensus on principles” 2009 *Forensic Sci Int Gen* 3:144–145.

interpreting DNA mixtures. Two papers were subsequently published on this topic: Dror and Hampikian⁸²⁰ published the first paper in 2011, testing the influence of irrelevant contextual information in the decision making process of forensic DNA experts based on a plea bargain case in Georgia. In a second paper in 2016, de Keisjer *et al.*⁸²¹ used a mock case simulating a violent robbery outside a bar. They provided the same following information and DNA profiles to 19 DNA experts:

“There is a male suspect, who denies any wrongdoing. The items that were sampled for DNA analysis are the shirt of the (alleged) female victim (who claims to have been grabbed by her assailant), a cigarette butt that was picked up by the police and that was allegedly smoked by the victim and/or the suspect, and nail clippings from the victim, who claims to have scratched the perpetrator.”

One examiner excluded the suspect as a possible contributor, another reported a match probability of 1 in 209 million, and the majority of the others declared the evidence as inconclusive. These errors triggered self-assessment within laboratories and a number of questions raised in criminal trials.

6.7.1 Events where DNA mixtures were challenged by self-assessment or the law

Many outside the forensic science community first heard about DNA mixture problems in August 2015 when the Texas Forensic Science Commission issued a statement detailing the issues that were discovered in various Texas forensic laboratories, after the FBI issued its amendments to

⁸²⁰ Dror IE and Hampikian G “Subjectivity and bias in forensic DNA mixture interpretation” 2011 *Sci & Justice* 51(4):204-208. In this case, one of the suspects implicated another in connection with a plea bargain. The two experts who examined evidence from the crime scene were aware of this testimony against the suspect and knew that the plea bargain testimony could be used in court only with corroborating DNA evidence. Due to the complex nature of the DNA mixture collected from the crime scene, the analysis of this evidence required judgment and interpretation on the part of the examiners. The two experts both concluded that the suspect could not be excluded as a contributor. Dror and Hampikian presented the original DNA evidence from this crime to 17 expert DNA examiners, but without any of the irrelevant contextual information. They found that only 1 out of the 17 experts agreed with the original experts who were exposed to the biasing information (in fact, 12 of the examiners excluded the suspect as a possible contributor).

⁸²¹ De Keijsers JW *et al.* “Differential reporting of mixed DNA profiles and its impact on jurists’ evaluation of evidence: An international analysis” 2016 *Forensic Sci Int Gen* 23:71-82.

their DNA population databases.⁸²² Initially, the two issues were conflated; however, the FBI mixture interpretation and database errors were two completely separate problems. When the FBI released their amended database, forensic DNA laboratories in Texas began re-doing the statistical conclusions on earlier cases samples at an attorneys' requests. The process required re-interpreting DNA mixtures utilizing new protocols and procedures that were adopted following the implementation of the 2010 Scientific Working Group on DNA Analysis Methods (SWGDM) Interpretation Guidelines for Autosomal STR Typing by Forensic DNA Testing Laboratories. It was then that the real problem was uncovered.

The re-interpretation of some of the more complexed DNA mixtures utilizing new adopted guidelines, indicated vast differences in the statistical conclusions. In fact, the possibility that a sample previously reported as an inclusion (meaning the individual of interest was found to be included as a contributor to the mixture) might now be reported as inconclusive (meaning that the laboratory could no longer include the same individual of interest as a contributor to the mixture), was high. The commission henceforth consulted with forensic experts to determine the large shifts observed in some cases and came to the conclusion that it had little or no relation to the corrections made by the FBI in their population database. The way in which forensic laboratories calculated the CPI statistic contributed more to the changes observed, especially how they dealt with phenomena such as "allelic dropout" at particular DNA *loci*. These developments piqued the interest of the defence community in Texas. Texas had been proactive with their re-examination of older DNA case evidence. This is not the case in majority of other states and jurisdictions within the United States.

Similar problems occurred elsewhere in other jurisdictions. On 18 September 2013, the Forensic Science Laboratory of the South African Police Service received their first blow in the appeal case of *Bokolo v S*,⁸²³ on the misinterpretation of a DNA mixture. A four-year-old girl from Harare, Khayelitsha, was found brutally raped and murdered and left in bushes 1.5km from her home, on

⁸²² Garcia L, Relevant documents and further details can be found at www.fsc.texas.gov/texas-dna-mixture-interpretation-case-review (Date of use: 17 March 2020). General Counsel for the Texas Forensic Science Commission, also provided a helpful summary to PCAST.

⁸²³ *Bokolo v S* (483/12) [2013] ZASCA 115. <http://www.saflii.org/za/cases/ZASCA/2013/115.pdf> (Date of use: 18 January 2020).

31 October 2004. A police officer placed two clean sanitary pads on her private parts to retain any fluid emanating therefrom. One of the two pads became the primary evidence in the trial, as it contained a mixture of DNA from at least three different male contributors. One contributor, the murder victim's own father, claimed not being near her during the time of the murder. He visited a drinking place and was escorted home and passed out after arriving at his home the previous night. At the appeal of the victim's father against his conviction on the charge of rape, a chief forensic expert, Colonel Otto was called by the state and Dr. Oosthuizen was called by the defense. The state expert testified on evidence recovered from the sanitary pad, which was divided into two pieces during the analysis. Both experts agreed on the value of the DNA profiles and procedures followed to obtain the electropherograms. At the time, nine STR *loci*, as well as the gender marker, were sufficient, although the UK tests included 11 *loci* and the US 13 *loci* and the gender markers.⁸²⁴ The dispute, however, was for allele 22 of the father at *locus* FGA (Fibrinogen Alpha Chain). Neither of the electropherograms reflected a peak labelled allele 22 at *locus* FGA. The state expert testified that:

"[...] at that point FGA 22:25, you will see that there is not a clearly marked 22 at FGA. A possible reason for this is that FGA is a huge — is one of the largest, how can I put it, largest areas in the DNA molecule, so obviously when you have DNA donated by quite a few people, you can actually lose some of your bigger fragments. So although there is not a labelled 22, we do have indications of DNA being present where we would expect to see a 22, so we can actually interpret it as such."⁸²⁵

To the counter the defence expert witness testified that:

"Because the height of a peak on an electropherogram is proportional to the quantity of DNA, alleles not detected in a less enriched sample of DNA may be indicated as a peak in the more enriched sample thereof. Therefore, a hint of DNA in a less enriched sample, if it represents DNA, should constitute a peak in the more enriched sample. A more enriched sample in this context simply means that it contains a greater quantity of the DNA than the less enriched sample. Pad 1 in this case contains a greater quantity of DNA than pad 2. Pad 1 is the sample more enriched with sperm and therefore the electropherogram thereof presents a much clearer picture than that of pad 2. There is a little block on the electropherogram of pad 2 that hints at DNA where one would find allele 22 at *locus* FGA. However, if that was DNA, it should have been represented as a labelled peak and

⁸²⁴ Meintjies-Van der Walt [43-44] and [84].

⁸²⁵ *Bokolo v S* (483/12) [2013] ZASCA 115 [26].

therefore an allele on 10 the electropherogram of pad 1. In the absence of any other explanation, it must be concluded that allele 22 cannot be detected at locus FGA on the electropherograms of either pad 1 or pad 2 and that the little block is in fact an artefact”⁸²⁶

Judge Van Der Merwe provided a comprehensive layout on his understanding of DNA and the value thereof. He however stated the following:

“If the STR profile of an accused person in fact differs from the profile retrieved from the sample taken at the scene, even in respect of only one allele, the accused person must be excluded as a source of the crime scene DNA. However, the converse is not true. Because only a limited number of STR loci are analysed, an STR profile cannot identify a person. Therefore, the weight to be attached to evidence of an STR profile match or inclusion in the first place depends on the probability of such a match or inclusion occurring in a particular population. Without such evidence the STR profile match or inclusion means no more than that the accused person cannot be excluded as a source of the crime scene DNA. If the profile in question may be found in many individuals, a match between the profile of the accused person and the crime scene DNA will have little or no probative value. This is of particular importance where the crime scene DNA is a mixture, which increases the likelihood that the profiles of other members of the population can be read into the mixture. On the other hand, an extremely rare profile will strongly point to the involvement of the accused person. This essential component of DNA evidence is usually presented in the form of statistical analyses of a population database.”⁸²⁷

Judge Van Der Merwe said that none of the reasons presented in the trial bear any scrutiny, but the relevance to the issue on which the experts disagreed, are based on the proper interpretation of the electropherograms. He stated that the defence expert had logical and cogent reasoning for the misinterpretation of the electropherogram by the state expert, and upheld the appeal. The conviction of Sandile Bokolo was set aside.⁸²⁸

The main problem in the above appeal case and similar examples revolves around the utilization of the Combined Probability of Inclusion (CPI) statistic. The CPI calculation is not problematic in and of itself, but the way laboratories apply the associated statistic to low-level data is what causes the problem. The original design of the CPI calculation was to provide an answer to the hypothetical question “given this set of DNA types at these DNA locations, what is the probability that another,

⁸²⁶ *Bokolo v S* (483/12) [2013] ZASCA 115 [27].

⁸²⁷ *Bokolo v S* (483/12) [2013] ZASCA 115 [21].

⁸²⁸ *Bokolo v S* (483/12) [2013] ZASCA 115 [34].

unrelated, individual other than the person of interest, could also be a contributor to the mixture". If a significant level of all the possible DNA types are present, and there are no indications of additional DNA types below the laboratory's reporting threshold, then the CPI statistic poses no threat on interpretation. But this is only possible in a perfect world, as multiple samples can yield complex DNA mixture profiles originating from low quantity amounts of DNA.

When low level DNA types are present, it may be a red flag that the sample suffered from stochastic effects, for example, random fluctuations that happened during the copying step (amplification) of the analytical process, which can contribute to absent DNA types. If some data is absent, then not all of the genotypes are represented. And, if some genotypes are absent, the CPI statistic is invalid. Dr. John Butler has reported repeatedly in his talks, books, and other presentations that the CPI statistic is unable to handle allele dropout and therefore examiners should not use unrestricted CPI calculations.⁸²⁹

The need for the standardisation of an approach, training and ongoing testing of DNA experts on complex mixtures has been suggested in an August 2016 scientific paper.⁸³⁰ The same paper recommends a set of rules necessary for the use of CPI statistics and for a scientific valid method.

IN 2017, SWGDAM recommended the use of two thresholds, namely the analytical threshold and the stochastic threshold, in an effort to help ensure that only the *loci* where all alleles are present are actually used in the statistical calculations. The analytical threshold was the height that a possible DNA type must reach before the forensic DNA laboratory considered the peak to be a "true" DNA peak, and not just noise or some sort of amplification artifact. The stochastic threshold had been defined by SWGDAM as:

⁸²⁹ 22nd International Symposium on Human Identification October 3, 2011 (Washington, DC) "Mixture interpretation: Using Scientific Analysis" Butler JM. *Unrestricted*: Referring to a statistical approach without consideration of quantitative peak height information and inference of contributor mixture ratios; for CPE/CPI this may or may not be conditioned on the number of contributors.

⁸³⁰ Bieber *Evaluation of forensic DNA mixture*.

“The peak height value above which it is reasonable to assume that, at a given locus, allelic dropout of a sister allele has not occurred”.⁸³¹

It was recommended that testing laboratories should set a stochastic threshold, based upon the validation of the particular instrument and amplification kit utilized, which provided a level of confidence on the certainty that dropout of data (alleles) had not occurred due to low levels of input material.

As a result of the challenges that have arisen, some researchers and software vendors launched efforts to develop “probabilistic genotyping” computer programs that applied algorithms to interpret complex mixtures. Since March 2014, eight known software programs had been developed, known as LRmix,⁸³² Lab Retriever,⁸³³ Like^{LTD},⁸³⁴ FST,⁸³⁵ Armed XpertTM,⁸³⁶ TrueAllele[®],⁸³⁷ STRmixTM,⁸³⁸ and DNA View Mixture Solution.^{839,840} Statistical software programs that incorporate probabilistic interpretation models overcame these limitations and fully utilise the available DNA typing information.^{841, 842, 843, 844} The computer algorithms and software applied biological

⁸³¹ SWGDAM “Interpretation Guidelines for Autosomal STR Typing by Forensic DNA Testing Laboratories” https://docs.wixstatic.com/ugd/4344b0_50e2749756a242528e6285a5bb478f4c.pdf (Date of use: 20 November 2018).

⁸³² Haned H and Gill P “Analysis of complex DNA mixtures using the Forensim package” 2011 *Forensic Sci Int Gen Suppl Series* 3:79–80. <http://lrmixstudio.org/> (Date of use: 16 February 2019).

⁸³³ Cheng K *et al.* “Scientific Collaboration, Innovation & Education Group” 2014. <https://scieq.org/lab-retriever/> (Date of use: 16 February 2019).

⁸³⁴ Balding DJ “Evaluation of mixed-source, low template DNA profiles in forensic science” 2013 *Proceedings of the National Academy of Sciences of the United States of America* 110(30):12241–12246. <https://www.isfg.org/Software> (Date of use: 16 February 2019).

⁸³⁵ OpenFst Library <http://www.openfst.org/twiki/bin/view/FST/WebHome> (Date of use: 16 February 2019).

⁸³⁶ Niche Vision Forensics LLC. <http://www.nichevision.com/index.php/forensics/armedxpert> (Date of use: 16 February 2019).

⁸³⁷ Perlin Validating TrueAllele[®] DNA mixture 2011.

⁸³⁸ Taylor D *et al.* “The interpretation of single source and mixed DNA profiles” 2013 *Forensic Science International: Genetics* 7: 516–528. <https://www.esr.cri.nz/our-services/products-and-tools/strmix/> (Date of use: 16 February 2019).

⁸³⁹ DNA-VIEW and PATER. <http://dna-view.com/downloads/info.html> (Date of use: 16 February 2019).

⁸⁴⁰ Butler JM “Chapter 13: Coping with Potential Missing Alleles” (Advanced Topics in *Forensic DNA Typing: Interpretation* (Waltham MA: Elsevier/Academic 2015) 333-348.

⁸⁴¹ Taylor D “The interpretation of single source” 2013.

⁸⁴² Perlin “Validating TrueAllele[®] DNA Mixture” 2011.

⁸⁴³ Balding “Interpreting low template” DNA 2009.

⁸⁴⁴ Gill P and Haned H “A new methodological framework to interpret complex DNA profiles using likelihood ratios” 2013 *Forensic Sci Int Gen* 7:251-263.

modeling, statistical theory, and probability distributions to enable experts to make inferences on the probability of the profile from single source and mixed DNA typing results.⁸⁴⁵ The software also generates likelihood ratios (LRs) to express the weight of DNA evidence given two user-defined propositions. It also demonstrates a more objective way of interpreting DNA typing results and is a more powerful tool supporting inclusion of contributors and the exclusion of non-contributors.⁸⁴⁶ Software programs are divided into two main groups: semi-continuous and continuous systems.⁸⁴⁷ Semi-continuous models (Lab Retriever, LikeLTD and LRmix) have the drop-out and drop-in probabilities, which calculate the likelihood that an allele may be absent or a false allele may be present. Peak height in these models are not used for information gathering, but sometimes used for the models' parameters. The software is open-source software for the public to use.

Haned *et al.*⁸⁴⁸ reported the use of a “gold standard” LR to evaluate the performance of the LRmix program when used to evaluate complex DNA mixtures of three to five donors. Continuous models (DNAmixtures, STRmix and TrueAllele) use allelic peak heights to calculate the weights assigned to the different genotype combinations. With their complexity, these models have more parameters to account for. With their Bayesian approaches,⁸⁴⁹ the models rely directly on empirical data generated during method validation. Model validation is complicated because the true weight of the DNA evidence cannot be determined, and no true LR can be calculated that can serve as a ground truth, as the generated LRs always depend on the model's assumptions.⁸⁵⁰ Most of the continuous models are commercially available and comes with a cost. It will be difficult to prescribe

⁸⁴⁵ Scientific Working Group on DNA Analysis Methods (SWGDM) “*Guidelines for the validation of probabilistic genotyping systems*”. https://1ecb9588-ea6f-4feb-971a-73265dbf079c.filesusr.com/ugd/4344b0_22776006b67c4a32a5ffc04fe3b56515.pdf (Date of use: 18 January 2020).

⁸⁴⁶ Taylor “Using continuous DNA interpretation” 2014.

⁸⁴⁷ Steele CD and Balding DJ “Statistical evaluation of forensic DNA profile evidence” 2014 *Annual Rev of Stats and its Application* 1:361–384.

⁸⁴⁸ Haned H *et al.* “Complex DNA mixture analysis in a forensic context: evaluating the probative value using a likelihood ratio model” 2015 *Forensic Sci Int Gen* 16:17-25.

⁸⁴⁹ Champod C *et al.* “Firearm and Tool Marks Identification: The Bayesian Approach” 2003 *AFTE J* 35(3):307-316. “The full application of Bayesian statistical inference takes prior beliefs about various possible competing hypotheses and then modifies these prior beliefs in the light of new data, which have been collected, in order to arrive at posterior beliefs. In other words, you use the data to update the prior (pre-test or pre-examination) beliefs to give posterior (post-test or post-examination) beliefs about the hypotheses you desire to estimate. Most examiners do not take a fully Bayesian approach to court but rather report the likelihood ratio.

⁸⁵⁰ Balding “Evaluation of mixed-source” 2013.

one single system for international DNA laboratories, as different laboratories have different needs and resources. They also function under different jurisdictions with their own requirements.⁸⁵¹

6.7.2 Legal challenges in response to the DNA software in DNA mixtures

DNA mixtures were again challenged in the appeal case of *United States vs. Anthony Shea*⁸⁵² in 1997. The defence of Anthony Shea argued that PCR cannot reliably detect mixtures of more than one person's DNA.⁸⁵³ In this case, the experts conceded that the mixture theory may lead to the declaration of a false match, but that such errors would be unlikely, because an examiner will be able to identify a mixture from observable differences in the relative strengths of the signals indicated on the PCR test strips. As a result, Judge Barbadoro rejected the defence's argument and accepted the testimony of the witness.⁸⁵⁴

Another United States case, *Winston v Commonwealth*,⁸⁵⁵ illustrates the problem with subjective analysis in a 2003 double homicide case. The prosecution expert reported that the defendant could not be excluded as a possible contributor to blood on a discarded glove that contained a mixed DNA profile of at least three contributors. The accused was convicted and sentenced to death, as the expert testified that the chance the match occurred by chance was 1 in 1.1 billion.

One of the first *Daubert* challenges using TrueAllele[®] software arose from an Indianapolis case, *Michael W.L. Deweese v State of Indiana*.⁸⁵⁶ At 4 am on November 9, 2014, two Indianapolis men invaded the Bloomington apartment of three University of Indiana students. The men robbed two of the women, and repeatedly raped them at gunpoint. Hidden in a closet, a third roommate called 911. Vaylen Glazebrook and Michael Deweese, both 19, were apprehended and charged with the crimes committed. Deweese pleaded guilty to rape, robbery, and attempted murder in 2016, and he was sentenced to 109 years in prison. Glazebrook elected to go to trial. The crime laboratory

⁸⁵¹ Balding "Evaluation of mixed-source" 2013.

⁸⁵² United States of America v. Anthony Mark Shea 1997.

⁸⁵³ US v. Shea [332].

⁸⁵⁴ US v. Shea [340].

⁸⁵⁵ *Winston v Commonwealth*, 604 S.E.2d 21 (Va. 2004).

⁸⁵⁶ *Deweese v. State*, 68 NE 3d 623 - Ind: Court of Appeals 2016.

analysed the DNA left on two firearms. The laboratory data showed complex DNA mixtures with up to five contributors, which the analysts could not interpret. The prosecution contacted Cybergenetics. The offenders and their victims' DNA were mixed together on the firearms. TrueAllele® computing unmixed the DNA data, and calculated match statistics.

TrueAllele® software analysis connected Glazebrook to both the firearms with DNA match statistics in the tens of millions. The computer software connected both victims to the firearms with numbers ranging from millions to quintillions. The analysis showed that Glazebrook's DNA was present - at the crime scene; on both victims, and on the firearms. On the morning of February 16, 2018, Dr. Mark Perlin of Cybergenetics testified at a *Daubert* hearing, establishing the software reliability. In the afternoon, Dr. Perlin presented the TrueAllele® evidence to a Bloomington jury. That evening, the jury convicted Glazebrook of attempted murder, four counts of rape, two counts of criminal confinement, burglary, robbery, and resisting law enforcement. On March 29, Glazebrook was sentenced to 125 years in prison.

On January 19, 2016, Karl Tuxford and Jordan Finlon were killed in revenge for a robbery they allegedly committed. Tuxford was found shot dead in his Jeep, while Finlon was discovered off of a road, with more than 40 stab wounds. The Manatee County Sheriff's Office submitted evidence, taken from a vehicle involved in the case, to DNA Labs International, a private forensic laboratory in Broward County, Florida, to process the DNA. By using STRmix™, DNA Labs International was able to determine that Dwayne Cummings and three unknown persons had contributed to the mixed DNA profile. Not only did the use of STRmix™ help to identify a perpetrator in the case, but it has also validated that STRmix™ was adequately robust enough for implementation in forensic laboratories and cases.⁸⁵⁷

On 26 October 2017, Hubert Moore (67) was randomly shot for eight dollars. Thaddus Nundra (38), a previous convicted felon had been released from prison a year before. The Georgia Bureau of Investigation (GBI) used Cybergenetics "TrueAllele" technology to connect complex DNA

⁸⁵⁷ Laura Burgess Marketing "*DNA Labs International Identifies Suspect in Double Homicide Case Using STRmix™*" 20 June 2017. <http://lauraburgess.com/dna-labs-international-identifies-suspect-double-homicide-case-using-strmix/> (Date of use: 3 December 2018).

mixtures to criminals. The Bureau linked Nundra to the scene of the shooting, and excluded two other men. His defence attorney challenged the software's reliability.

On December 11, 2018, Judge Craig Earnest held an admissibility hearing on TrueAllele's scientific reliability. Cybergenetics chief scientist, Dr. Mark Perlin, testified about TrueAllele reliability. GBI DNA analyst, Emily Mathis testified about her TrueAllele work on the case. Judge Earnest found "TrueAllele" to satisfy the Harper standard. He stated that substantial evidence has been presented to the Court, which supports the admission of TrueAllele analysis, and no significant evidence has been presented to the contrary. He also found the probabilistic genotyping admissible at trial. The trial started Monday, February 11 and GBI's Mathis testified about her TrueAllele DNA mixture results. Later that week, the Decatur County jury convicted Nundra of killing Moore and sentenced him to life in prison.

This was a breakthrough for "TrueAllele" software designers and for those crime laboratories who use the software in their analytical interpretation procedures. It was a first step towards a more objective interpretation of DNA mixtures by using a reliable software procedure. Although a novice application accepted in court, it still had a long way to go to gain complete acceptance in the larger forensic science community.

6.7.3 Extension of CODIS Core Loci and STRmix™ validation

In 2015, the FBI announced that the validation project for additional CODIS Core Loci had been completed and that an additional seven *loci* would be added to the CODIS Core, effective January 1st, 2017.⁸⁵⁸ It increased from 13 to 20 *loci* and therefore provided a higher discriminatory power between individuals and increased the probabilistic weight in testimony. A complete validation study on STRmix™, the software used by the FBI, was also published in July 2017⁸⁵⁹ by experts from the FBI, New Zealand and Australia. Their findings supported STRmix™ software to be

⁸⁵⁸ Hares DR "Selection and implementation of expanded CODIS core loci in the United States" 2015 *Forensic Sci Int Gen* 17:33-34. <https://www.fbi.gov/services/laboratory/biometric-analysis/codis> (Date of use: 4 December 2018).

⁸⁵⁹ Moretti TR *et al.* "Internal validation of STRmix™ for the interpretation of single source and mixed DNA profiles" 2017 *Forensic Sci Int Gen* 29:126-144.

sufficiently robust for implementation in forensic laboratories. The software offers numerous advantages over historical methods on DNA Profile analysis as well as greater statistical power for the estimation of evidentiary weight and could be used reliably in human identification. This evaluation provided a model in accordance with SWGDAM recommendations for internal validation of a probabilistic genotyping system for DNA evidence interpretation.

One month after the PCAST report, the 18th Interpol International Forensic Science Managers review paper⁸⁶⁰ was published on important developments that occurred during the years 2013 to 2016.⁸⁶¹ Researchers focused on Screening devices and amplification, Rapid DNA analyses, analyses of complex DNA profiles, and the development of Next-Generation Sequencing (NGS) and its application to DNA Phenotyping. Researchers were able to decrease analytical time with the development of rapid PCR protocols, reducing the time required for amplification to less than one hour.⁸⁶² They were also able to reduce a three-step protocol to a two-step thermal cycling protocol.⁸⁶³ Other research allowed practitioners to avoid the extraction and quantification stages in the analytical workflow for reference samples, by using a direct PCR kit.⁸⁶⁴

In April 2016, the FBI provided NDIS approval for the Accelerated Nuclear DNA Equipment (ANDE) device. The fully integrated device allowed practitioners to generate full STR profiles using the PowerPlex® 16 chemistry within 84 min.⁸⁶⁵ The device contained an automated allele calling expert system and RFID sample tracking. Evaluation of the success of the CODIS core *loci* was 10 % lower than the 95 % success rate observed in reference laboratories for 100 buccal swabs

⁸⁶⁰ 18th INTERPOL International Forensic Science Managers Symposium Lyon, France, 11-13 October 2016 Review Papers.

⁸⁶¹ 18th Interpol symposium 2016 [697-705].

⁸⁶² Romsos EL and Vallone PM “Rapid PCR of STR markers: Applications to human identification” 2015 *Forensic Sci Int Gen* 18:90–99.

⁸⁶³ Frégeau CJ and Laurin N “An Accelerated Analytical Process for the Development STR Profiles for Casework Samples” 2015 *J Forensic Sci* 60:983–989.

⁸⁶⁴ Oostdik K *et al.* “Developmental validation of the PowerPlex® Fusion System for analysis of casework and reference samples: A 24-locus multiplex for new database standards” 2014 *Forensic Sci Int Gen* 12:69–76. Also, Scherer M *et al.* “Development of the Investigator STR GO! Kits for the direct amplification of reference samples” 2013 *Forensic Sci Int Gen Suppl Series* 4:15–16. Also, Flores S *et al.* “Internal validation of the GlobalFiler™ Express PCR Amplification Kit for the direct amplification of reference DNA samples on a high throughput automated workflow” 2014 *Forensic Sci Int Gen* 10:33–39.

⁸⁶⁵ Tan E *et al.* “Fully integrated, fully automated generation of short tandem repeat profiles” 2013 *Investig Gen* 4:16.

tested. In contrast, the RapidHIT™ 200 integrated device also utilised the PowerPlex® 16 chemistry and provided success rates of 95 % with an ability to run seven samples simultaneously.^{866, 867, 868}

The above mentioned developments ensured faster sample preparation times with less human involvement, which will ultimately lead to faster results and reports for court hearings and a more objective approach, avoiding human errors in analytical work through automation.

Research on the NGS also demonstrated improvements in this methodology. The NGS methodology steadily found its way into crime laboratories, replacing the Snapshot analysis that has been used for many years. Forensic science laboratories had more choices and had to determine what their needs were and whether or not a global method or a more specific one was preferred.

NGS kits allowed for an increased number of *loci*, which led to more data and helped practitioners to reach more conclusive and confident results. Another advantage is that different classes of polymorphism could be analysed together. It was predicted that simple NGS kits will streamline testing by simultaneously analysing large numbers of globally relevant STR markers and dense SNP sets in a single test. One of the major changes was that sequences from the minor contributor in 1:100 and 1:50 mixtures were detectable by NGS, whereas minor contributors less than 1:10 were usually not detectable using traditional methods.⁸⁶⁹

Researchers continued moving towards faster sample preparation, automation, lowered costs and more *loci* detail for higher discriminatory ratios. The Interpol report provides a more comprehensive overview of some of these issues.⁸⁷⁰

⁸⁶⁶ LaRue BL *et al.* "An evaluation of the RapidHIT™ system for reliably genotyping reference samples" 2014 *Forensic Sci Int Gen* 13:104-111.

⁸⁶⁷ Holland M and Wendt F "Evaluation of the RapidHIT™ 200, an automated human identification system for STR analysis of single source samples" 2015 *Forensic Sci Int Gen* 14: 76–85.

⁸⁶⁸ Hennessy LK *et al.* "Developmental validation of the GlobalFiler® express kit, a 24-marker STR assay, on the RapidHIT® System" 2014 *Forensic Sci Int Gen* 13:247-258.

⁸⁶⁹ Børsting C *et al.* "Evaluation of the Ion Torrent™ HID SNP 169-plex: A SNP typing assay developed for human identification by second generation sequencing" 2014 *Forensic Sci Int Gen* 12:144–154.

⁸⁷⁰ 18th Interpol symposium 2016 [697-710].

6.8 Future developments within forensic biology

Similar to forensic drug chemistry, forensic biology/DNA will continuously be tested for its scientific validity in judicial proceedings. It would also be important for the DNA community to acknowledge past challenges and failures, both in serology and DNA, and keep striving for zero defects and threats in future analysis and interpretation. Dr. Butler stated in one of his papers that:

“Accurately predicting the future is always challenging due to unforeseen innovation. However, by examining the past and understanding present challenges, it is often possible to extrapolate to reasonable predictions for the future.”⁸⁷¹

Butler also sees the evolution of DNA profiling in four different stages, namely exploration (1985-1995), stabilisation and standardisation (1995 - 2005), growth (2005 – 2015), and sophistication (2015 -2025).

6.8.1 Assessment of key aspects in DNA evidence based on past experiences

The following key aspects should be assessed, based on past experiences:

- The use of serology should not be discarded with the use of DNA analysis. There is still great value in serological testing of forensic biological evidence and the two could complement each other during investigations.
- Forensic crime laboratories should find a way to balance technology, sensitivity and data interpretation.
- Crime laboratories should ensure sufficient funding for scientists to stay proficient within this ever changing field. The training should be directed towards new technology, interpretation of mixture software and a true understanding of probability statistics.
- Legal professionals, judges and juries should also be better educated on the basic concepts of DNA analysis, validation, interpretation and probabilistic values of DNA evidence in court. There should be minimum training requirements on DNA for jurors and legal professionals.

⁸⁷¹ Butler “Future of forensic DNA” 2015.

- Accreditation, certification, quality control and validation should be mandatory in each crime laboratory and not just a “nice to have”. This should include blind proficiency testing on single and mixture samples.
- Standardisation entities, such as OSAC and ENFSI, should continue with research and development processes and the implementation of national and international standards.
- Internationalisation of DNA databases should be explored, but with caution so as to not violate the rights of the innocent.
- New technology and interpretation software should undergo vigorous testing before their implementation in crime laboratories. It is the continuous trial-and-error concept that will lead to the loss of integrity in the method.
- The use of Familial DNA searches should only be an option when all other avenues for successful prosecution had been explored and did not harvest any fruits.

6.8.1.1 The continued use of serology

The use of serology in criminal investigations dated back for over a hundred years with some success. Research on improving serological tests have been exhausted over the years with multiple peer-reviewed articles published and books written. With the discovery of DNA in the 1980s, serology started to lose its value in criminal proceedings, especially with exonerations of innocent felons based on faulty or overstated ABO results. This led to questions about the validity and use of serology on crime scene samples and what value it contributes in modern biological examinations. The validity of the tests should still be the same, as many of the tests followed the process of validation of being a scientific method; however, the probabilistic value changed with the introduction of DNA. Although some laboratories use rapid screening test, there still is, and will be, for many years to come, a place in crime scene investigation for serological tests. For example, the testing for biological fluids or stains at crime scenes will always be needed. It will always be a supporting aid for forensic scientists and should be used in such a way that its value is clearly defined, yet not overstated.

6.8.1.2 The balance between technology, sensitivity and data interpretation

The future of Forensic DNA testing was described by Butler⁸⁷² with three Latin words (which are also the motto of the Olympic Games) – *Citius, Altius, Fortius* – which means faster, higher, stronger. There is a continual quest to receive forensic DNA results faster from crime laboratories. Rapid DNA system technology is one such discovery that allows for faster DNA results. The technology integrates (1) DNA extraction, (2) Rapid PCR amplification of more than 15 STR *loci*, (3) DNA separation, (4) detection, (5) sizing and, (6) genotyping. Results for “swab-in” to “profile out” of five buccal swab reference samples are minimised to less than 90 minutes, but comes with a high reagent cost. One concern with the Rapid DNA system technology is that quality might be sacrificed for speed. Improved detection sensitivity, expanded sets of core STR *loci*, supplemental genetic markers, and deeper information from sequence analysis of alleles will all provide higher amounts of information. With the improved sensitivity in PCR assays and profile generated content, more data are now becoming available from biological evidence. The increased sensitivity also has a challenge associated with low quantity DNA mixtures, especially during DNA profile interpretation. There is a misconception that a relevant DNA profile can be obtained from a single cell from a crime scene. Although it is true that a DNA profile could be obtained from a single cell, it may not always be relevant to the crime event being investigated, and that should be kept in mind during testimony. Fundamental limits exist with PCR amplification when it comes to sensitivity. Stochastic effects, as discussed earlier in this chapter, produce peak height differences for heterozygous samples during PCR amplification. At low sensitivity (100-125pg), stochastic effects such as elevated stutter and allele drop-out occur even with single source samples. Allele drop-out also occurs when the number of PCR amplification cycles are increased to improve sensitivity. It is challenging for forensic experts to confidently pair alleles into genotypes and correctly separate individual contributors in DNA mixtures, if stochastic variations occur. With low-level DNA amplification and lower sensitivity, uncertainty can increase during interpretation. Probabilistic genotyping approaches were developed to explain the observed data using computer simulation software to determine an estimate of the relative contributions of multiple contributors. The algorithmic approaches are constantly challenged in courts and a single acceptable package has

⁸⁷² Butler “Future of forensic DNA” 2015.

not been approved by any standardising body. Crime laboratories have to establish a complexity threshold to avoid poor quality data interpretation and testimony. Technological advances increased the sensitivity in DNA profiling, but outpaced the reliable interpretation of data generated. It is, therefore important for experts to know the limitations of their testimony, and clearly communicate those limitations-of-interpretation approaches to avoid improper use of DNA evidence. Technology changes allow forensic scientists to use less subjective opinions and start to rely more on technology to produce answers through algorithmic coding.

Stronger conclusions from challenging complex data is probably the largest future venture for the DNA discipline. Challenges can come from failed PCR inhibitors that produce weak profiles in degraded DNA samples. Therefore, it is important for crime laboratories to carefully consider the cost of new technology, sensitivity thresholds, and established algorithmic models that will support interpretation of generated data.

6.8.1.3 Sufficient training of scientists

With the fast-paced technological developments, crime laboratories are constantly challenged to replace outdated instrumentation, and more importantly, to keep their scientists current through training and development. With budget constraints and the cost of external training interventions, scientists fall behind in their ability to defend DNA results using outdated equipment. However, many vendors of equipment and software provide free web training and tutorials to assist crime laboratories, but scientists do not receive credit for attending or utilising these. A number of scientists may not have a strong foundation in statistics and can easily be overwhelmed when Bayesian theorems or other statistical theorems surface. A good grasp of statistical approaches will provide a good foundation for supporting conclusions. Stronger supporting conclusions using probabilistic approaches can only be accomplished if the scientists understand the validation of the software used, as well as knowing the limitations associated with the software. The meaning of the results should also be communicated clearly to legal professionals, juries and judges. This should include good record keeping, communicating limitations of methods, models, assumptions made, and interpretations applied to the final results. Forensic scientists should stay current with technological changes. Even if the equipment used in their laboratories might be outdated, they

might be questioned about new developments in the field during court hearings. A well-established scientist is recognised by his or her ability to stay abreast of developments in the discipline and participate with his or her peers on a regular basis in events relating to the latest scientific developments in their domain.

6.8.1.4 Minimum training requirements for legal professionals and jurors

For many years, concerns were expressed about the lack of understanding of forensic science among judges and lawyers. Anecdotal opinion suggests that legal professionals often enter law schools in order to avoid mathematics and science, but later in their careers have to face the exact thing they tried to avoid. Faigman⁸⁷³ states that the scientific sea is very wide and deep and judges should at least know how to swim i.e. “have the basic skills necessary to read and understand scientific methods and to integrate scientific knowledge in their legal decisions, without actually having to make the swim across the entire breadth of science”. However, since 1995, the breadth of knowledge through scientific research has exploded in such a way that not even scientists are able to keep abreast with all the new developments. Meintjies van de Walt⁸⁷⁴ states that “[k]nowledge of the different theories, as well as the way in which the law views science, is crucial to participants in the legal process when scientific evidence is introduced.” The myth of the existence of autonomous, unambiguous and objective scientific truths must be dispelled. More so, judges are faced with making decisions as “gatekeepers” in regard to scientific and expert testimony. It is therefore important for legal professionals to understand the scientific fundamentals underpinning forensic evidence. It is also important for legal professionals and judges to understand the technological advances made when it will be applied in their courtrooms. Earlier efforts made by the National Institute of Justice in 2012 resulted in a training module called “DNA for the Defense Bar”,⁸⁷⁵ allowing legal professionals to enrich themselves on the basic knowledge of DNA evidence. Koen and Bowers⁸⁷⁶ authored a book, “Forensic Science Reform: Protecting

⁸⁷³ Faigman DL “Mapping the labyrinth of scientific evidence”, 1995 *Hastings Law J* (46):579.

⁸⁷⁴ Meintjies-Van der Walt L “The proof of the pudding: the presentation and proof of expert evidence in South Africa” 2003 *J of African Law* 47:91.

⁸⁷⁵ National Institute of Justice “DNA for the Defense Bar” NCJ 237975, June 2012.
<https://www.ncjrs.gov/pdffiles1/nij/237975.pdf> (Date of use: 28 August 2019).

⁸⁷⁶ Koen WJ and Bowers CM “Forensic Science Reform: Protecting the innocent” (Academic Press 1st ed December 2016).

the innocent”, to help simplify complicated scientific information for attorneys and judges. The intent was also to assist prosecuting attorneys on the state of forensic sciences in order to avoid reliance on legal precedent that is lagging behind the science. In 2016, the United States Department of Justice proposed a number of standards for expert testimony in forensic disciplines, which were challenged by the PCAST report later in the same year.

Efforts made by the West Virginia University Law School, in collaboration with the WVU Forensic Department, to create an L.L.M in forensic science sadly lacked interest from legal fraternity and was placed on hold after three years. Besides these efforts, other programs on a regional and state level offer annual one- or two-day courses to educate legal professionals on forensic science. If it takes two years of foundational STEM courses for scientists to become forensic scientists, a two-day course will provide a bare minimum of information to a legal professional in the criminal justice system. Justice departments should audit the current state of affairs within the justice system and determine what the standardised minimum requirement of training for legal professionals practicing in criminal proceedings ought to be. There are jurisdictions that understand the need to establish Forensic commissions, such as the Texas Forensic Science Commission, which consists of Judges, prosecuting and defence attorneys, forensic scientists and academics that promote training and developments amongst all stakeholders within the criminal justice system.⁸⁷⁷

6.8.1.5 Accreditation, certification and validation

To promote confidence in DNA testing, quality assurance measures had to have been developed, implemented, and tested over the last three decades. The DNA testing quality infrastructure in forensic crime laboratories is one of the most advanced structures in any of the other forensic disciplines. The quality structure was built from the foundations of strong organisations, such as the European Network of Forensic Science (ENFSI), European DNA Profiling group (EDNAP), Federal Bureau of Investigation’s DNA Advisory Board (DAB), Scientific Working Group on DNA Analysis Methods (SWGDM), and more recently, OSAC. With such a strong structural foundation on quality assurance and quality control, it is hard to believe that not all forensic DNA entities are

⁸⁷⁷ Texas Judicial Branch, Texas Forensic Science Commission. <https://www.txcourts.gov/fsc/about-us/>
(Date of use: 17 January 2020).

accredited or forensic experts working in those laboratories are certified. It can again be attributed to the lack of regulation from Justice Departments. The value of independent endorsement through accreditation will demonstrate competence to the court when performing specialised tasks. Accreditation will ensure regular assessments, by picking up non-conformance or non-compliance within the laboratory that might have been overlooked. Accreditation bodies also provide additional support and technical advice, online resources, training courses, and access to published scientific papers.

Certification from independent organisations will lead to the endorsement of scientists having similar questions and similar professional value. The certification should encompass a written examination on theory, statistics and ethics, followed by practical challenges and troubleshooting exercises, mentor and mentee programs, and lastly, proficiency testing (preferably blind proficiency tests). Mandatory certification should be required of crime laboratory directors.

Once scientists are well versed in the discipline, validation of new techniques should require minimal effort. Many laboratories avoid formal validation because it takes time and resources. Formalised validation can also support the competency of the laboratory and demonstrate low error rates associated with DNA analyses.

6.8.1.6 Continuous research and development in the field

Similar to any other scientific field, continued research is necessary to further enhance the field to achieve sophistication. Forensic DNA analysis went through exploration, stabilisation and standardisation, growth, and is now in the sophistication stage. Research should be focused on higher capacity results in shorter turnaround times, which are cost effective with simplified data analysis and interpretation. Despite millions of dollars spent in the last three decades on DNA research, it is disappointing that the forensic community still experiences so many challenges within the discipline. There may be a variety of reasons for this, such as, insufficient distribution of research papers within the community; lack of interest from practitioners to study research papers to decide if new techniques may work within their crime laboratory; lack of accountability on poor research efforts, cutting the financial support to those entities; and the inability to accept change

and adopt new ideas that may work. Funding should be allocated to successful researchers who produced acceptable results through research papers in peer-reviewed journals. Crime laboratories should collaborate with academia, as there is presently a disconnect with regard to what is routinely needed in the crime laboratory, and what specific interests the academic researcher should be pursuing.

6.8.1.7 Internationalisation of DNA databases

Increased information content is now present in DNA profiles with an expanded number of required core *loci* for inclusion in national DNA databases. With the expanded number of core *loci* required, international data exchange is also promoted across various databases. However, longer time is required to interpret all the data once they are exchanged. Many of the software systems are open-source and free of charge, which makes them easy to implement in casework. The software may represent a first step for forensic laboratories before they introduce more complex models. They also offer an ideal framework for international collaborative efforts, whereby jurisdictions globally can admit data retrieved from such databases during trials without having the validity of the database used, questioned.

6.8.1.8 Rigorous testing of new techniques and interpretation software

New technologies are regularly introduced and validated to expand the capabilities of laboratories working to generate DNA results with improved sensitivity. Forensic laboratories have embraced automation, for sample preparation and data interpretation, in order to meet increasing throughput demands. Short tandem repeat (STR) typing continues to be the primary workhorse in forensic DNA analysis, although other genetic markers are used for specific applications.

Next generation sequencing (NGS) has provided opportunities to collect information from multiple STRs and SNPs simultaneously. It also provides a depth of information by characterising internal sequence variation for same size alleles, which is not possible with Capillary Electrophoresis methods. Another advantage of NGS methodology is that mtDNA genome sequences can also be generated on this method. The key to all new techniques and experimental research work is to

bear in mind that what is interesting for research may not always be practical or necessary in routine analyses by crime laboratories.

Microbial DNA transfer also shows some potential in profiling sources and may be a supporting aid to investigations. The transfer can occur by touching objects on a crime scene or during sexual intercourse. Microbial DNA analysis will be performed with NGS or other high-throughput methods to avoid additional DNA backlog samples.

It is expected that no one single expert system or software data interpretation package will be adopted by the entire forensic DNA community. Different laboratories have different needs and resources, and diversity in methodology can be expected. This reflects the view that there is no one true LR and the statistics produced will depend on the models' parameters and assumptions. In the context of forensic science investigations, different software can be used to cross-check the results for a given case, and this is a practice that should be encouraged. Comparative studies on large datasets, representative of the challenges encountered in casework, will further help the understanding of the advantages and limitations of the different systems. Such comparisons are essential, as they will assist forensic laboratories to choose a particular system that will complement their internal procedures, their validation criteria, and the workflow. Once laboratories have consensus on a particular system, jurisdictions can with confidence admit the evidence as scientifically valid.

6.8.1.9 The use of familial DNA

When profile searches fail to find matching data in the database, expanded searches can be performed by relaxing the stringency of the primary search and using genetic inheritance principles to produce “familial” searches. Familial searching has shown a low level of success, because of the lack of close relatives of the true perpetrator in a relevant database.⁸⁷⁸ It could also result in

⁸⁷⁸ Niedzwiecki *Understanding Familial DNA* June 2017.

long false-positive candidate lists, due to common alleles that are shared by unrelated people.⁸⁷⁹ However, using Y-STR testing on male samples from ranked candidate lists can filter the false positives. Familial DNA searches still has a long way to go before it will be implemented on a national level in the United States, but has shown promising results in the United Kingdom during the last decade. Privacy challenges arising in many jurisdictions often involve controversial language (e.g. PM versus FDS searches) used in policies and procedures relating to Familial DNA database searches.⁸⁸⁰

Regarding forensic ancestry testing using Y-chromosome markers, future work needs to provide a better grasp of the geographic distribution of many of the recently discovered Y-SNPs, to establish how useful they are for improving the geographic resolution of paternal ancestry inference. It is expected that such knowledge will allow paternal bio-geographic ancestry inference to be moved from the current level (of mostly continental resolution) to a much more detailed geographic resolution. As with Y-STRs, the limitation for Y-SNPs in multiplexing capacity of the genotyping technologies currently used in forensic DNA analysis has to be overcome, in order to take full advantage of the large number of Y-SNPs needed to infer bio-geographic ancestry on a detailed level. Here, current targeted Massively Parallel Sequencing (MPS) technologies are highly promising because of their large multiplex capacity, together with their short sequencing reads, given the single base pair nature of Y-SNPs

6.9 Conclusion

On many platforms, DNA analysis is considered the gold standard in forensic science. Even with all the successes, the discipline still experiences challenges and failures, and needs to overcome

⁸⁷⁹ Rohlf R et al. "The Influence of Relatives on the Efficiency and Error Rate of Familial Searching" 2013 *PLoS One* 8(8):70495. <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3743829/> (Date of use: 9 January 2020).

⁸⁸⁰ Niedzwiecki *Understanding Familial DNA* 2017. The FBI (n.d.) distinguishes FDS from PM as follows: "A partial match...is the spontaneous product of a routine database search where a candidate offender profile is not identical to the forensic profile but because of a similarity in the number of alleles shared between the forensic profile and the candidate profile, the offender may be a close biological relative of the source of the forensic profile. Familial Searching is an intentional or deliberate search of the database conducted after a routine search for the purpose of potentially identifying close biological relatives of the unknown forensic sample associated with the crime scene profile."

the problems associated with mixture interpretation challenges. The science of DNA is well received in legal settings, yet a better integration and harmonisation between the law and science should always remain a priority. Although the biological evidence is known to yield the highest exoneration counts, it is the developments within the field of forensic science that established new methods to exonerate falsely convicted individuals on insufficient scientific evidence in the past. The scientific methodology within the discipline, if applied correctly, is valid, reliable and repeatable. The community continues to search for solutions on DNA mixture profiles to reach a more objective opinion when interpreting data. It is clear that a one-size-fit-all approach will not be possible, as crime laboratories have different needs and approaches when it comes to software applications in data interpretation.

New technology should first be tested to withstand the larger DNA community before it is rolled out in smaller crime laboratories. The “trial-and-error” phase is over and better coordinated implementation processes are required to replace older techniques.

As stated in an earlier chapter, legal professionals should find ways to work closer with scientists to exchange legal and scientific challenges. Both entities need to collaborate more closely to establish a uniform linguistic dictionary where words such as “error” has the same meaning in all legal proceedings across jurisdictions. This concordance of terms and definitions should be regularly updated.

Once ASTM standards are developed and approved, legal authorities should make these mandatory for use by crime laboratories in an effort to minimise the conviction of the innocent.

Chapter 7 Friction ridge evidence

7.1 Introduction

In the past, pattern evidence disciplines were referred to as the non-science forensic sciences that have little or no basis in actual sciences. These disciplines were accused of neither borrowing from established science nor systematically testing their hypotheses. Their validity claim was supported by anecdotal experience and the proclamation of success over time. Where many scientific fields will use experience and observations as a first step of the scientific method, pattern interpretation has been seen as the terminal process of the method. Their claim to individualisation, which by some implies uniqueness,⁸⁸¹ is also one of their biggest obstacles in the science arena, and challenged by many. Some saw this as untested systems before being offered as testimony (testify first-validate later).^{882,883}

This study will look at two distinct disciplines on pattern interpretation evidence, namely friction ridge evidence (chapter 7) and firearm and tool mark evidence (chapter 8). These are two disciplines that use individuality and uniqueness interchangeably in testimonies historically, but recently changed due to new recommendations.⁸⁸⁴ It is important to study the historical development to determine their foundational validity as a science in the broader field of forensic science. The reason for selecting fingerprints and firearms is similar to selection of controlled substances in chemistry, the first-mentioned constitutes the majority of patterned evidence samples received by crime laboratories are.⁸⁸⁵

⁸⁸¹ Thornton JI and Peterson JL “The General Assumptions and Rationale of Forensic Identification” in (Faigman D *Modern Scientific Evidence: The Law and Science of Expert Testimony* (4th ed West Group 2008).

⁸⁸² Cooley CM “Forensic Individualization Sciences and the Capital Jury: Are Witherspoon Jurors More Deferential to Suspect Science than Non-Witherspoon Jurors?” 2004 (28) *S ILL U Law J* 273.

⁸⁸³ Pyrek K *The Challenges of Forensic Laboratories and the Medico-Legal Investigation System, Forensic Science under Siege* (Academic Press 1st ed February 2007).

⁸⁸⁴ Department of Justice “Approved uniform language for testimony and reports for the forensic latent print discipline” 2018-09-24. <https://www.justice.gov/olp/page/file/1083691/download> (Date of use: 20 January 2020).

⁸⁸⁵ “Forensic Science 2030” *Forensic Magazine* 2013.

7.2 Introduction and development of dermatoglyphics and scientific methodology

7.2.1 Early scientific discoveries on dermatoglyphics to support uniqueness and permanence

7.2.1.1 Uniqueness of fingerprint evidence

As is the case in any science, scientists need to know and understand physical and chemical properties of the evidence they are working with before experimental work commences. In the case of fingerprint analysis, it was important for scientists to know where ridge formations are coming from and the fundamentals supporting their existence in the universe. Two fundamental premises had to be tested, namely: (1) the uniqueness theory of ridge patterns and (2) the persistence of patterns over time.

Previous research in the field of fingerprints conventionally focused on various characteristics associated with fingerprint ridge formations. The focus of early studies was on Ridgeology (study of ridge formation and patterns), followed by studies on Edgeoscopy (study of the edges of ridges), poroscopy (focusing on sweat pores on ridges), and incipient ridges (small ridges between distinct ridges).

In 1904, Inez Whipple published the paper, “The Ventral Surface of the Mammalian Chiridium”. Whipple’s survey into mammalian palm and sole configurations formed an important part of the modern scientific knowledge on the subject and is considered a landmark in the fields of genetics and Ridgeology.⁸⁸⁶ Her paper describes the evolution of friction ridge skin and its development. She provides locations of the volar pads and explains possible forces that affect ridge growth.⁸⁸⁷

⁸⁸⁶ Ashbaugh DR *Quantitative-Qualitative Friction Ridge Analysis* (CRC Press NY 1999).

⁸⁸⁷ Whipple IL “The Ventral Surface of the Mammalian Chiridium. *Zeitschrift für Morphologie und Anthropologie*” 1904 *J of Morphology and Anthropology* 7:261–368.

In 1918, Wilder and Wentworth exemplified how, through joint effort, the fields of science and law enforcement could function together. In their book, "The identification of individuals",⁸⁸⁸ Wilder and Wentworth state as follows:

"The patterns of the friction skin are individual, and, taken together, impossible to duplicate in another individual. The separate ridges, too, show numerous details, which are also so individual that a small area of friction skin, taken even in the most featureless portion, cannot be matched by any other piece."

This statement was a strong statement on using partial prints for comparisons.

In 1914, Dr. Edmond Locard published, "The Legal Evidence by the Fingerprints". Locard was Director of the Laboratory of Police at Lyons, France, and was a student of Alphonse Bertillon. Locard's 1914 article, and others published soon afterwards, explained the theory of poroscopy (poroscopy later became part of 3rd level detail in comparisons)⁸⁸⁹ and how the use of pores could supplement a fingerprint comparison by lending supporting data. His study into the sweat pores of friction ridge skin was one more example of how law enforcement personnel were conducted research into fingerprint science.⁸⁹⁰ Locard stated that a minimum of eight minutiae points was required for positive fingerprint identification.⁸⁹¹ It was four more minutiae points as previously claimed by Inspector Collins in 1905, who was working at the Scotland Yard at the time.⁸⁹²

⁸⁸⁸ Wilder HH and Wentworth B *Personal Identification: Methods for the identification of individuals living or dead* (The Gorham Press 1918).

⁸⁸⁹ National Institute of Justice *Fingerprint Sourcebook* Chapter 9 2005 [9-8]. 1st level detail of friction ridge features is the general overall direction of ridge flow in the print. First level detail is not limited to a defined classification pattern. Every impression that is determined to be a friction ridge print has a general direction of ridge flow, or first level detail. 2nd level detail is the path of a specific ridge. The actual ridge path includes the starting position of the ridge, the path the ridge takes, the length of the ridge path, and where the ridge path stops. Second level detail is much more than the specific location of where a ridge terminates at a ridge ending or bifurcation, or its Galton points. 3rd level details are the shapes of the ridge structures. This level of detail encompasses the morphology (edges, textures, and pore positions) of the ridge.

⁸⁹⁰ Locard E "La Preuve Judiciaire par les Empreintes Digitales" (The Legal Evidence by the Fingerprints). *De Médecine Légale et de Psychologie Normale et Pathologique* (Of Forensic Medicine and of Normal and Pathological Psychology)" 1914 29:321.

⁸⁹¹ Ashbaugh "Quantitative-Qualitative Friction Ridge Analysis" 1999.

⁸⁹² Cole SA *Suspect Identities: A History of Fingerprinting and Criminal Identification* (Harvard University Press 2001). Also, Lambourne G *The Fingerprint Story* (Harrap: London 1984).

In 1962, Salil Kumar Chatterjee of Calcutta, India, published an article “Edgeoscopy”,⁸⁹³ in which he described his theory of using specific ridge-edge shapes to supplement fingerprint individualisation. He defined ridge shapes including straight, convex, peak, table, pocket, concave, and angle. Chatterjee believed that these edge shapes could be used to assist in making individualisations.⁸⁹⁴ The mentioned ridge detail also formed part of 3rd level detail in fingerprint comparisons until today. This was the first scientific research supporting third level detail as permanent and unique.

More studies were needed to determine the degree of variability among the prints of different fingers (inter-finger variability), and also, the degree of variability within prints made by the same finger (intra-finger variability).

Dermatoglyphic research continued throughout the 20th century, but was outside the scope of forensic science. In 1973, Mavalwala⁸⁹⁵ published a book with an extensive bibliography on dermatoglyphics, with over 3 000 references, excluding the use of dermatoglyphics in law enforcement. It became a valuable resource for research on level 1 features on fingers and palm prints in a range of populations.

In 1976, Dr. Michio Okajima of Japan published the paper,⁸⁹⁶ “Dermal and Epidermal Structures of the Volar Skin”. The main contribution from his work was the study of incipient ridges, which appear as smaller ridges in friction ridge impressions. Babler’s contribution⁸⁹⁷ on a full overview of studies conducted in the 20th century on embryologic development of friction ridge skin, starting around 10 weeks post-fertilization, covered a comprehensive understanding of the development of the hand, volar pads, the epidermal ridges, and dermal papillae. He also highlighted the factors affecting ridge configuration, including topography of volar pads, surface distribution of nerves, growth stress, and bone development. It was also discovered that no genetic information is carried

⁸⁹³ Chatterjee SK “Edgeoscopy” 1962 *Fingerprint and Identification Magazine* 44(3):3-13.

⁸⁹⁴ Ashbaugh *Quality* 1999 [160].

⁸⁹⁵ Mavalwala J *Dermatoglyphics, an International Bibliography* (Chicago: Mouton Publishers 1977).

⁸⁹⁶ Ashbaugh *Quality* 1999 [58].

⁸⁹⁷ Babler WJ “Embryologic Development of Epidermal Ridges and Their Configurations” 1991 *Dermatoglyphics- Sci in Transition* 27(2):95-112.

over to friction ridge development, and that not even identical twins developed distinguishable ridge patterns.⁸⁹⁸

Wertheim and Maceo published a paper in 2002 on their research of ridge pattern development. They argued that ridge counts are mainly affected by two temporal events, namely the onset of epidermal cellular proliferation, and the timing of the regression of the volar pads. They also stated that pattern types are affected by the position of the volar pads. The work of Kücken,⁸⁹⁹ published in 2007, disagreed with the second statement of Wertheim and Maceo, as Kücken maintained that the pattern arises as a result of a folding process in the cell layer of the epidermis during embryologic development.

In the 2010 review paper of the 16th International Forensic Science Symposium, titled “Fingermarks”, more research developments and discoveries were addressed on topics such as papillary skin features, morphogenesis, general characteristics, creases, level 2 detail, twin studies, level 3 detail and distortion (references 94-141).⁹⁰⁰

Based on numerous studies and discoveries, the variability of friction ridge skin patterns became accepted as a sound scientific basis when used to distinguish individuals. The next question that remains to be answered, is whether from a scientific perspective, this uniqueness remained the same over time.

7.2.1.2 Fingerprint Permanence

Early discoveries, as will be discussed, described fingerprint features as immutable and unalterable naturally, and were seen as permanent from womb to death. The hypothesis of fingerprint permanence has been well supported in the scientific literature. Permanence was first studied prior to the early era of forensic fingerprint identification by Hermann Welcker,⁹⁰¹ who conducted a study

⁸⁹⁸ Jain AK et al. “Can Identical Twins Be Discriminated Based on Fingerprints?” 2000 Technical Report MSU-CSE-00-23, Department of Computer Science, Michigan State University, East Lansing, Michigan.

⁸⁹⁹ Kücken MU “Models for Fingerprint Pattern Formation” 2007 *Forensic Sci Int* 171(2-3):85-96.

⁹⁰⁰ 16th International Forensic Science Symposium *Fingermarks* 2010.

⁹⁰¹ Wilder and Wentworth 1918.

from 1856 to 1897 (41 years), using his own right palm print. He found that both impressions appeared to be identical in detail over the period. At the same time, Faulds⁹⁰² and Galton⁹⁰³ performed similar studies of repeated fingerprints taken over time. In 1916, Herschel⁹⁰⁴ conducted the first study, involving multiple subjects, by taking their prints after a 57-year period. These results supported the hypothesis of permanence.

Studies continued in 1979 by Okajima,⁹⁰⁵ in 2002 by Wertheim and Maceo,⁹⁰⁶ and 2003 by Wan *et al.*,⁹⁰⁷ to establish a scientific basis for permanence in fingerprint features. They all established that permanent modification of ridge detail by physiological means can only transpire through destruction of the dermis layer of the skin. David *et al.*,⁹⁰⁸ observed that scarring and various skin conditions may challenge the permanence of fingerprint features. Okajima⁹⁰⁹ also studied other influences, such as advanced ageing, which are associated with flattening of surface ridges and loss of elasticity in the dermis, and ultimately result in a less visible ridge pattern. Later studies by Wong *et al.*⁹¹⁰ indicated that medical side effects, for example, those caused by Capecitabine, can remove fingerprint ridge pattern detail. Gottschlich *et al.*⁹¹¹ referred to all of these changes or modifications as isotopic rescaling. Permanence is therefore not guaranteed. Only if a person's finger is kept under controlled conditions and certain illnesses do not occur to that individual that may influence ridge patterns, can permanence be claimed. It can hence be said that fingerprint permanence is conditional and has limitations.

With the scientific foundations established on uniqueness and permanence, proper use in a forensic setting had to be established. The information would give forensic examiners confidence

⁹⁰² Faulds H "On the skin furrows of the hand" 1880 *Nature* vol 22(574):605.

⁹⁰³ Galton *Finger Prints* 1892.

⁹⁰⁴ Herschel WJ *The Origin of Finger-printing* (Oxford University Press, London 1916).

⁹⁰⁵ Okajima M "Dermal and epidermal structures of the volar skin" 1979 *Birth Defects Orig Artic Ser* 15(6):178-198.

⁹⁰⁶ Wertheim K and Maceo A "The critical stage of friction ridge and pattern formation" 2002 *J Forensic Ident* 52(1):35-85.

⁹⁰⁷ Wan H *et al.* "Desmosomes Exhibit Site-Specific Features in Human Palm Skin" 2003 *Experimental Dermatology* 12(4):378-388.

⁹⁰⁸ David TJ *et al.* "Fingerprint Changes in Coeliac Disease" 1970 *Br Med J* 4(5735):594-596.

⁹⁰⁹ Okajima "The volar skin" 1979.

⁹¹⁰ Wong M *et al.* "Travel warning with Capecitabine" 2009 *Annals of Oncology* 20(7):1281.

⁹¹¹ Gottschlich C *et al.* "Modeling the growth of fingerprints improves matching for adolescents" 2011 *IEEE Trans Inf Forensic Sec* 6(3):1165-1169.

on the scientific foundation of known prints (ten prints) from a known source. It is the quality of discovered unknown prints, or parts thereof that poses the biggest obstacle for successful comparisons by the examiner.

The functions of skin were covered in a contribution by Freinkel and Woodley,⁹¹² which was highly commended by Maceo⁹¹³ in 2003. Although not written for forensic science, it allows forensic practitioners to understand how the human body functions when producing fingerprint residue left behind at crime scenes.

Moenssens and Jamieson edited a scholarly publication in Wiley Encyclopedia of Forensic Science⁹¹⁴ with a range of papers on fingerprints and human marks and the individualisation process.

7.2.1.3 The composition of latent print residue

The previous two sections discussed the anatomy of the skin and in this section the relevance of ridge formation and permanence thereof for crime scene investigation will be discussed.

Every time an individual touches a surface or an object with his or her bare hands, a residue in the form of sweat will be transferred. Discoveries made on the complexity of sweat composition⁹¹⁵ helped researchers in the fingerprint community to find new ways to develop and preserve latent prints from crime scenes. Research conducted by Bernier *et al.*⁹¹⁶ provided more insight on the

⁹¹² Freinkel RK and D Woodley *The Biology of Skin* (Parthenon Publishing Group: New York 2001).

⁹¹³ Maceo A "The Biology of Skin" 2003 *J Forensic Ident* 53(5):585-591.

⁹¹⁴ Moenssens A and Jamieson A *Wiley Encyclopedia of Forensic Science* (Wiley Blackwell 2009).

⁹¹⁵ Ramotowski R "Composition of Latent Print Residue" In: *Advances in Fingerprint Technology* Lee HC, Gaensslen RE eds (CRC Press: Boca Raton, FL 2001) 63–104. Also: Bramble SK and Brennan JS "Fingerprints (Dactyloscopy): Chemistry of Print Residue" In: *Encyclopedia of Forensic Science* Siegel J, Saukko P and Knupfer G, eds (Academic Press: London 2000) 862–869.

⁹¹⁶ Bernier UR *et al.* "Analysis of Human Skin Emanations by Gas Chromatography/Mass Spectrometry: 1. Thermal Desorption of Attractants for the Yellow Fever Mosquito (*Aedes Aegypti*) from Handled Glass Beads" 1999 *Anal Chem* 71 (1) 1–7. Also: Bernier UR *et al.* "Analysis of Human Skin Emanations by Gas Chromatography/Mass Spectrometry: 2. Identification of Volatile Compounds That Are Candidate Attractants for the Yellow Fever Mosquito (*Aedes Aegypti*)" 2000 *Anal Chem* 72 (4):747–756.

chemical composition of human sweat. It is important for latent examiners to understand the chemical composition and chemical changes of sweat residue after deposition to ensure successful visualisation of quality prints. Decisions made in this phase is similar to those made in chemical extraction in controlled substances or DNA extraction from biological evidence. The quality of a good comparison is directly dependent on the quality of the development of the latent print. A wrong decision made by the examiner, due to the lack of knowledge of the chemical composition and behavior of fingerprint residue, will produce low quality or prints of no value for continuation. Two primary glands that contribute to the production of residue that might be found on crime scenes; are:

- sudoriferous glands which produce a water-based residue with trace quantities of eccrine and apocrine (commonly found on the palms of the hands, soles of the feet, neck and back, and from hair glands of the armpit and pubic areas);⁹¹⁷ and
- sebaceous glands which produce a more lipid-based residue (commonly found on the scalp, face, nose, mouth and external ear areas).

Eccrine and apocrine trace quantities contain mostly a series of amino acids,⁹¹⁸ which form the foundation of chemical developments of latent fingerprints. Finding sebaceous sweat residue in latent fingerprints from crime scene evidence is not uncommon as perpetrators would touch their face area or other parts of the body multiple times a day like all humans do, before touching objects on the crime scene. This will leave residue that is water-soluble and water-insoluble with a combination of amino acids, proteins and lipids, which allow for chemical reactions that will produce coloured visualisation of ridge formations on porous or non-porous substrates.

⁹¹⁷ Anderson KN *et al. Mosby's Medical, Nursing, and Allied Health Dictionary* (Mosby Inc 5th ed St. Louis MO 1998).

⁹¹⁸ Brusilow SW and Gordes EH "Ammonia Secretion in Sweat" 1968 *Am J Phys* 214 (3):513–517. Also: Mitchell HH and Hamilton TS "The Dermal Excretion under Controlled Environmental Conditions of Nitrogen and Minerals in Human Subjects, with Particular Reference to Calcium and Iron" 1949 *J Biol Chem* 178 (1):345–361. Also: Sato K "The Physiology, Pharmacology, and Biochemistry of the Eccrine Sweat Gland" 1979 *Rev Physiol Biochem Pharmacol* 79:51–131.

Having knowledge of the chemical and physical properties of the residue allowed researchers to expand from only using powders in latent print development to other physical and chemical developments. This will be discussed under physical and chemical discoveries in latent fingerprint development in this chapter.

7.2.2 *Early recordkeeping and uses of fingerprints*

A turning point in the use of fingerprints for identification was the fallibility of anthropometric measurements discovered in 1903, with the arrest of William West. His measurements and photograph indicated exact similarities with his brother Will West who was already in prison.⁹¹⁹ It was later determined that they were identical twins with easily differentiated fingerprints. The discovery showed the fallibility of an established system used in the identification of individuals and its replacement by a single biometric system, called finger mark identification.

The use of fingerprints was not originally designed to be used solely for criminal cases, but rather as a means of identification or authentication of individuals, for example prison systems, military sign-up and border control. In 1918, Wilder and Wentworth published a book, "Methods for the identification of individuals, living or dead",⁹²⁰ explaining the use of fingerprints beyond police work. In the preface of their book they stated the following:

"Up to the present the main use of such scientific methods of bodily identification has been confined to the identification of the criminal classes, whose practices render them notably elusive as to personality; yet there are countless other cases where the identification of

⁹¹⁹ Cole *Suspect Identities* 2001. "A man was arrested in 1903 and brought to the Leavenworth prison in Kansas. The man claimed that his name was Will West and that he had never been previously arrested. Prison personnel took the man's Bertillon measurements and his photograph to facilitate a prison records check. The records showed that a man named William West, with very similar anthropometric measurements and a striking resemblance to the new inmate, was already incarcerated in Leavenworth prison. Guards sent to check William West's cell may have suspected they were dealing with an escapee; instead, they found William West asleep in his bed. After comparing records of both men, prison personnel seemed unable to tell the men apart. Upon taking and comparing the fingerprints of both prisoners, it was clear that the fingerprint method of identification could distinguish between the two men."

⁹²⁰ Wilder HH and Wentworth B *Methods for the identification of individuals, living or dead* (The Gorham Press Boston USA 1918). Also, https://archive.org/stream/cu31924007451101/cu31924007451101_djvu.txt (Date of use: 02 March 2019).

individuals is equally necessary, and where the ordinary methods of recognition are insufficient. The liability to accidents involving the mutilation of the face, the frequency with which a man's mind may become temporarily or permanently beclouded, the temptation to fraud often felt by men who do not belong distinctly to the criminal class, attempts of impostors to claim estates; these and numerous other possibilities render some sure method of bodily identification one of the great necessities of civilization. Such a system would be of great value to families, insurance companies, banks, industrial institutions, and all great business enterprises involving responsibility for employees. The need is present in schools and hospitals, especially maternity hospitals, and those for the insane, while, in time of war, as at the present moment, comes the pressing need of adequately identifying all enlisted men, however numerous they may be. The need of individual identification is imperative, too, in the case of passports, railroad passes and all kinds of legal papers involving and bestowing special privileges which are non-transferable.

This problem of individual identification has thus passed already far beyond the walls of police stations and penitentiaries, and the demand is seen, more and more clearly, for some method of universal identification embracing all the citizens of the Nation. The science of individual identification through the various bodily peculiarities has now quite outgrown the prison walls, in which it was nurtured, and is ready to fill the place which the growing needs have made for it.”⁹²¹

It was a clear statement that the fingerprint science community did not just belong to law enforcement, but encompasses a larger community due to its scientific validity.

As more individuals studied fingerprint patterns and possible uses of these, its popularity grew and more entities and countries followed the uniqueness of the friction ridges assigned to each individual. Recordkeeping of this uniqueness of fingerprints and using it for multiple purposes gained popularity on a global level. A turning point was reached when the uniqueness outgrew older systems used in individualisation.

7.2.2.1 Early Fingerprint Systems

Authorities in many countries slowly became convinced that fingerprint uniqueness could stand on its own in the identification of individuals and led to the development of fingerprint systems. Table 7.1 below provides a summary of fingerprint systems applied in various jurisdictions.

⁹²¹ Wilder *Methods for the identification* 1918 [5].

Table 7.1 Timetable of early fingerprint systems and events in various countries:

Country	Year	Event
British India	1897	Fingerprint system first replaced anthropometry
New Scotland Yard	1901	First Fingerprint system ⁹²²
Australia	1901	Adopted the Hendry fingerprint system when Sam McCauley, Deputy Controller of Prisons in New South Wales, studied the use and fingerprint classification at Scotland Yard, and recommended it should be part of the New South Wales goals. Soon after the same system was introduced to other states in Australia and New Zealand. ⁹²³
United States of America	1902	Fingerprint science was adopted when Dr. Henry P. DeForest, Chief Medical Examiner of the New York Civil Service Commission, started fingerprinting all civil service applicants. ⁹²⁴
	1903	Captain James H. Parke of New York State developed the first American Classification System in the State Prison Department (Albany), after several months of fingerprinting criminals upon their release. It was the first systematic use of fingerprinting for criminal record purposes in the United States. ⁹²⁵
	1904	Inspector John K. Ferrier of Scotland Yard, gave the fingerprinting instruction to American officers. He and Major M. W. McClaughry began collecting fingerprint cards of all inmates at the Leavenworth, Kansas, federal prison. It was the beginning of the U.S. Government's fingerprint collection. ⁹²⁶
	1906	The War Department of the United States adopted a fingerprint system, fingerprinting all incoming recruits.
	1906	The Bureau of Police, Chicago, under the auspices of Captain Michael Evans, implemented the first 8 x 8-inch fingerprint record

⁹²² Polson CJ "Fingerprints and Fingerprinting" 1951 *J Crim Law Criminology and Police Sci* XLI:690.

⁹²³ Australian Police <https://www.australianpolice.com.au/dactyloscopy/fingerprint-identification-in-australia/> (Date of use: 31 December 2018).

⁹²⁴ DeForest H "Henry de Forest Papers" 1898-1947, Collection Number: 3214 Division of Rare and Manuscript Collections, Cornell University Library.

⁹²⁵ McGinnis PD "American System of Fingerprint Classification; New York State Department of Correction, Division of Identification" New York 1963.

⁹²⁶ Myers HJ "History of Identification in the United States" 1938 [19–20].

	cards with a vertical filing system. The same size card is still used internationally today.
1907	The Bureau of Navigation, United States of the Navy, adopted the fingerprint system. ⁹²⁷
1908	The US Marine Corps adopted the fingerprint system.
1916	The first organised school for the teaching of finger printing was established by the Institute of Applied Science, Chicago. In the same year, Frederick Kuhne published a book, titled "The finger print instructor" ⁹²⁸ in the US, based upon Sir Edward Henry's book (System of Classification and Filing).
1919	The first American technical journal on finger printing, titled "Finger Print and Identification Magazine", was distributed in Chicago. ⁹²⁹ It was a medium used to distribute information on new discoveries and developments on finger marks.
1923	The Ninth Session of the International Police Conference held in New York adopted a classification system, developed by Hakon Jorgensen, ⁹³⁰ for identifying individuals using information from single fingerprints. This system, called Distant Identification, utilised about fifty numerals of coded fingerprint information which could be transmitted by telephone, telegraph, or radio. The fingerprint of John Meehan (alias "Bull") was the first case where a finger print was telegraphically transmitted between the police departments of New York and Chicago. ⁹³¹
1924	The collections from Leavenworth and the files of the National Police Bureau of Criminal Identification were combined (810,188 records). The Identification Division in the U.S. Justice Department's Bureau of Investigation was established.

⁹²⁷ "Fingerprint and Identification" *Magazine Volumes 4-5 Volume 24 1942*: 28.

⁹²⁸ Kuhne F and Henry ER *The finger print instructor* (New York Munn Company Inc 1916).

⁹²⁹ "Fingerprint and Identification" 1942.

⁹³⁰ Jorgensen H "Distant Identification and One- finger Registration" 1923 *Publications of International Police Conference* Police Department New York.

⁹³¹ Fingerprint and Identification Magazine 1942.

1933	The Division of Investigation of the United States' Department of Justice installed a single finger-print system.
1940	The first national registration of aliens to the United States was established and during a period of 4 months (August 27 to December 26), 4,667,839 individuals (aliens) were finger printed. ⁹³²

For the purpose of this study, the focus will be on the application of fingerprint use as evidence in criminal proceedings.

By 1924, in order to determine or locate a suspect by means of police files, it was necessary to find a set of all of the suspect's finger-prints at the crime scene. Standard systems of classification were based upon all ten patterns.⁹³³

After the use of the single fingerprint system, suspicion was frequently narrowed down to several individuals whose recorded prints were then compared, and an identification made. Occasionally the memory of an expert enabled the location of an appropriate file because of familiarity with the details of the evidence print (which would be considered biased today).

Comparisons are only possible if a latent print can be enhanced, then lifted or imaged, and taken back to the laboratory for examination. Knowing the physical and chemical properties of the latent prints assisted scientists to develop powders and chemicals for physical and chemical enhancement of latent print evidence on crime scenes.

⁹³² Fingerprint and Identification Magazine 1942.

⁹³³ Henry ER *Classification and Uses of Fingerprints* (George Routledge and Sons Ltd 1900). Digital edition prepared for <http://galton.org/fingerprints/books/henry/henry-classification.pdf> (Date of use: 02 March 2019).

7.2.3 Introduction of physical and chemical discoveries in latent print development

From as early as the 1800s, finding prints on crime scenes posed a challenge for investigators. Unseen prints, better known as latent prints, had to be treated to enhance the prints characteristics before they could be compared to a known (ten print) specimen. Many factors influence the quality of the transferred (deposition) of a latent print. Robert Olsen described those factors in his book published in 1978, "Scott's Fingerprint Mechanics".⁹³⁴ The condition or health of the donor's friction skin and the composition and quantity of sweat residue on the skin is called the pre-transfer deposition, and the conditions are affected by the age, gender, stimuli, occupation, disease, and any substances the subject may have touched prior to deposition.⁹³⁵ At the time of deposition, conditions such as surface (substrate) being touched, including texture, surface area, surface curvature or shape, surface temperature, condensation, contaminants, and surface residues, would dictate the quality of the print.⁹³⁶ Lastly, environmental conditions in post-transfer, for example, physical contact from another surface, water, humidity, and temperature will also affect the quality of the print.⁹³⁷

Based on these conditions, physical and chemical enhancement analytical schemes had to be designed before the quality and quantity of a print could be determined to be used for comparison. Table 7.2 provides a list of discoveries made on physical and chemical developments.

Table 7.2 Discoveries made on physical and chemical developments of latent prints

Technique	Year	Use
Photographic images	1859	Used to support an expert's opinion in court as to how comparisons were made.
	Early 20 th century, Folmer and Schwing manufacturing	Helped examiners with little to no photographic experience to capture 1:1 life-sized images for comparison and court purposes. ^{938, 939}

⁹³⁴ Olsen Scott's "Fingerprint Mechanics" 1978.

⁹³⁵ Olsen Scott's *Fingerprint Mechanics* 1978 [118–120].

⁹³⁶ Olsen Scott's *Fingerprint Mechanics* 1978 [117–122].

⁹³⁷ Olsen Scott's *Fingerprint Mechanics* 1978 [121–122].

⁹³⁸ Moenssens "Fingerprint Techniques" 1971.

⁹³⁹ Olsen Scott's "Fingerprint Mechanics" 1978.

Fingerprint powder	1891	Dusting various surfaces for the potential to enhance a latent print physically was and still is one of the oldest methods used by examiners on crime scenes. ⁹⁴⁰ Charcoal, lead powder, and cigar ashes were some of the substances used to make powders and were applied on surfaces at crime scenes. ⁹⁴¹
	1904	Inspector John Kenneth Ferrier, of New Scotland Yard remained in the United States to teach fingerprinting, including how to use powder to develop latent prints. ⁹⁴²
Ninhydrin	1910, Siegfried Ruhemann	Discovered that a new developed compound reacted with the amino acids of skin and produced a purple colour. ⁹⁴³
	1954	Ruhemann's discovery solved the problem and provided the ability of a certain chemical to turn fingerprint residue purple on porous substrates found its application in forensic science. ⁹⁴⁴
Fluorescence with UV	1933	A method of visualising latent fingerprints after dusting with anthracene powder on multicolored surfaces. ⁹⁴⁵ This methodology was enhanced over years where various light sources in the visible electromagnetic range (violet light with the highest energy and shortest wavelength (400nm) to red light with the lowest energy and the longest wavelength (700nm)) were used to examine produced fluorescence in latent prints (through the application of fluorescent fingerprint powders). When the correct barrier filters were used to block out the light from forensic light source, but not the emitted light from the fluorescence, a high signal-to-noise ratio was

⁹⁴⁰ Forgeot "Etude medico-legale des empreintes" 1891.

⁹⁴¹ Moenssens "Fingerprint Techniques" 1971.

⁹⁴² Myers HJ II "The First Complete and Authentic History of Identification in the United States" 1938 *Finger Print and Ident Mag* 20 (4):3–31.

⁹⁴³ Ruhemann S "Cyclic Di- and Tri-Ketones" 1910a *J Chem Soc Trans* 97:1438–1449.

⁹⁴⁴ Odén S and von Hofsten B "Detection of Fingerprints by the Ninhydrin Reaction" 1954 *Nature* 173(4401):449–450.

⁹⁴⁵ Inbau FE "Scientific Evidence in Criminal Cases, Part III: Finger-Prints and Palm-Prints" 1934 *Sparks from the Anvil* 2(12):4.

		observed separating the background from the developed fingerprint ridges. ^{946, 947, 948}
Ninhydrin “analog”	1980s	Ninhydrin-hemiketals were prepared to enhance the specificity of reactions with various amino acids on porous substrates.
1,8-Diazafluoren-9-one (DFO) 5-Methylthioninhydrin (5-MTN)	1990	1,8-Diazafluoren-9-one (DFO) was explored in 1990. ^{949,950} 5-Methylthioninhydrin (5-MTN) first prepared in 1990. ⁹⁵¹ A summary of discoveries Ninhydrin and analogs was captured by Almog in Chapter 5 of the book compiled by Lee and Gaensslen. ⁹⁵²
Iodine fuming	1940	Latent fingerprint visualisation using iodine fumes. ^{953,954,955,956} At first, it was believed that the iodine fumes reacted reversibly to the double bonds of the unsaturated fatty acids in fingerprint residue through the process of halogenation, but Almog <i>et al.</i> ⁹⁵⁷ suggested that the mechanism involved physical absorption rather than chemical reaction.

⁹⁴⁶ Menzel ER and Duff JM “Laser Detection of Latent Fingerprints—Treatment with Fluorescers” 1979 *J Forensic Sci* 24(1):96–100.

⁹⁴⁷ Menzel “Fingerprint Detection” 1999.

⁹⁴⁸ Menzel ER “*Fingerprint Detection with Photoluminescent Nanoparticles*” In: Lee HC and Gaensslen RE *Advances in Fingerprint Technology* (CRC Press: Boca Raton, 2nd ed FL 2001).

⁹⁴⁹ Pounds CA *et al.* “The Use of 1,8-Diazafluoren-9-one (DFO) for the Fluorescent Detection of Latent Fingerprints on Paper, A Preliminary Evaluation” 1990 *J Forensic Sci* 35(1):169–175.

⁹⁵⁰ Grigg R *et al.* “1,8-Diazafluorenone and Related Compounds. A New Reagent for the Detection of α-Amino Acids and Latent Fingerprints” 1990 *Tetrahedron Lett* 31 (49):7215–7218.

⁹⁵¹ Cantu AA *et al.* “A Comparative Examination of Several Amino Acid Reagents for Visualizing Amino Acid (Glycine) on Paper” 1993 *J Forensic Ident* 43(1):44–66.

⁹⁵² Almog J “*Fingerprint Development by Ninhydrin and Its Analogues*” Chapter 5, Lee HC and Gaensslen RE *Advances in Fingerprint Technology* (2nd ed in Forensic and Police Science, Fisher BAJ CRC Press: Boca Raton 2001).

⁹⁵³ Olsen Scott’s “Fingerprint Mechanics” 1978.

⁹⁵⁴ Rhodes HTF *Forensic Chemistry* (Chemical Publishing New York 1940).

⁹⁵⁵ Bridges BC *Practical Fingerprinting* (Funk and Wagnalls New York 1963).

⁹⁵⁶ Moenssens “Fingerprint Techniques” 1971.

⁹⁵⁷ Almog J *et al.* “Chemical reagents for the development of latent fingerprints. II. Controlled addition of water vapor to iodine fumes — a solution to the ageing problem” 1979 *J Forensic Sci* 24:431.

Cyanoacrylate	1950s	Developed as an acrylic polymer adhesive for the aircraft industry. ⁹⁵⁸
	1970s	Researchers in Japan and United Kingdom discovered the development of latent fingerprints on non-porous substrates from the fumes of the liquid adhesive. ⁹⁵⁹
Vacuum Metal Deposition	1964	Prof. Samuel Tolansky noted that the deposition of silver in a vacuum system accidentally developed a fingerprint on a glass component. ⁹⁶⁰
	1968	French workers reported that a mixture of zinc, antimony, and copper powder was capable to develop fingerprints on paper. ⁹⁶¹
	1972	A range of metals was used to develop fingerprints on paper and fabrics. ⁹⁶²
Fingerprints in blood	1911	Abderhalden and Schmidt reported the development of fingerprints on a ninhydrin bottle. ⁹⁶³
	1954	Oden produced ninhydrin formulations in acetone for the development of fingerprints in blood. ⁹⁶⁴
	1961	Godsell introduced the use of Amido black in solvent base as a chemical of use in fingerprint development in blood. ⁹⁶⁵

Table 7.2 does not depict all the discoveries made in fingerprint development, however, but it covers major discoveries outside and within the field of forensic fingerprint development. It provides evidence that not all discoveries were made solely for fingerprint development, but some techniques used outside the field were applied to fingerprint development, with great success.

⁹⁵⁸ NIJ *Fingerprint Sourcebook* Chapter 7 [23].

⁹⁵⁹ NIJ *Fingerprint Sourcebook* Chapter 7 [23].

⁹⁶⁰ NIJ *Fingerprint Sourcebook* Chapter 7 [34].

⁹⁶¹ Theys P *et al.* "New Technique for Bringing Out Latent Fingerprints on Paper: Vacuum Metallisation" 1968 *Int Crim Police Rev* 217:106–109.

⁹⁶² Hambley DS "*The Physics of Vacuum Evaporation Development of Latent Fingerprints*" (Ph.D. Thesis The Royal Holloway College University of London 1972).

⁹⁶³ Abderhalden E and Schmidt H "Utilization of Triketohydrindene Hydrate for the Detection of Proteins and Their Cleavage Products" 1911 *Z Physiologische Chem* 72:37.

⁹⁶⁴ Odén "Detection of Fingerprints" 1954.

⁹⁶⁵ Godsell J "Fingerprint Techniques" 1963 *J Forensic Sci Soc* 3(2):79.

7.2.4 Application of scientific methodology in forensic settings

Prior to the 1950s, little to no information existed on validation studies to determine limitations and challenges that practitioners could experience when using various types of dusting materials in physical developments. It was either a hit-or-miss process when powders were applied on both non-porous surfaces (surfaces where the amino acid or sweat residue stays on the surface) and porous surfaces (amino acid or sweat residue absorbs into the surface medium).

Lee and Gauesslen capture the formulations of various powders (black powders, magnetic powders, coloured powders, and fluorescent powders) in their contribution, "Advances in Fingerprint Technology".⁹⁶⁶ Although Ninhydrine was discovered in 1910, its acceptable reaction mechanism and use and application in forensic science was suggested by Friedman and Williams only in 1974.⁹⁶⁷

Cyanoacrylate fuming entails the polymerization process of the alkyl-2-cyanoacrylate ester (Super Glue) on fingerprint residue on surfaces as diverse as plastics, electrical tape, garbage bags, Styrofoam, carbon paper, aluminum foil, finished and unfinished wood, rubber, copper and other metals, cellophane, rubber bands, and smooth rocks.⁹⁶⁸ The cyanoacrylate fuming procedure and several modifications of it that accelerate the development of latent prints are discussed by Lee and Gauesslen.⁹⁶⁹ One of the advantages of the polymerization process was to preserve and protect the fragile latent print on objects before being packaged and transported from crime scenes to crime laboratories for further enhancements.⁹⁷⁰ Although cyanoacrylate fuming is an excellent method for processing, the latent prints developed by this procedure often lacked contrast and were difficult to visualise due to background noise. Dusting became the most common post-

⁹⁶⁶ Lee HC and Gaensslen RE eds. "Advances in Fingerprint Technology" In: Chapter 4, Series 2nd ed *Forensic and Police Science* Fisher BAJ (CRC Press: Boca Raton 2001).

⁹⁶⁷ Friedman M and Williams LD "Stoichiometry of formation of Ruhemann's purple in the ninhydrin reaction" 1974 *Bioorganic Chem* 3: 267.

⁹⁶⁸ Lee HC and Gaensslen RE "Cyanoacrylate fuming — theory and practice" 1984 *Ident News* 34:8.

⁹⁶⁹ Lee *Advances in Fingerprint Technology* 2001 [132-134].

⁹⁷⁰ Perkins DG and Thomas WM "Cyanoacrylate Fuming Prior to Submission of Evidence to the Laboratory" 1991 *J Forensic Ident* 41(3):157–162.

treatment procedure used by practitioners to enhance the contrast. Alternative post-treatment further enhanced polymerized prints by exposing print to dyes (Dye stains) in solution, or by using compounds that luminesce or fluoresce under UV, laser, or other illumination. Newer applications combined the two-step process and the cyanoacrylate, which are pre-treated with a dye stain, before fuming. Czubak investigated commercially available cyanoacrylate glues for fingerprint enhancement.⁹⁷¹ Menzel compiled a comprehensive review on the use of nanoparticles to reveal latent fingerprints on crime scene evidence.⁹⁷²

In 2004, the 14th International Forensic Science Symposium literature review⁹⁷³ recognised a variety of papers on variabilities in chemical development of latent prints on porous surfaces, which included humidity, solvent effects, substrate type and, exposure time. It also highlighted chemical improvements used in the enhancement of prints in blood. The literature review report concludes with research performed on the evaluation of alternative light sources, imaging and digital enhancement of developed prints and lastly methodology used in background or artifact subtraction during enhancements.

More validation studies performed by Brettell *et al.*⁹⁷⁴ were reported in *Analytical Chemistry* and also contain a literature review in fingermarks and developments, which was further supported by Druce and Bristow⁹⁷⁵ dealing with fingerprint detection techniques.

Over time, fingerprint identification became part of a larger field, called “biometrics”, and publications in this field incorporated a number of papers in an Encyclopedia published by Springer Verlag.⁹⁷⁶ Publications of relevance included an overview of the forensic applications,⁹⁷⁷ fingerprint

⁹⁷¹ Czubak A “The use of cyanoacrylate glues for revealing fingerprints on various surfaces” 2002 *Z Zagadnien Nauk Sadowych- Problems of Forensic Sci LII*:87-94.

⁹⁷² Menzel *Fingerprint Detection* 2001 [211-240].

⁹⁷³ 14th International Forensic Science Symposium Lyon France in 2004 [14-19].

⁹⁷⁴ Brettell T *et al.* “Forensic Science” 2009 *Anal Chem* 81:4695-4711.

⁹⁷⁵ Druce JF and Bristow LC “Latent Mark Development and Analysis within a Modern Policing Environment” 2010 *Surface and Interface Analysis* 42:343-346.

⁹⁷⁶ Li SZ and Jain A *Encyclopedia of Biometrics* (New York: Springer Verlag, 2009).

⁹⁷⁷ Champod C “Forensic Applications, Overview” in *Encyclopedia of Biometrics* Li SZ and Jain A eds. (New York: Springer Verlag 2009) 563-569.

matching,⁹⁷⁸ and cognitive processing in fingerprint recognition.⁹⁷⁹ In another Springer Verlag contribution, “Handbook of Biometrics” by Flynn *et al.*,⁹⁸⁰ a chapter was dedicated to the relationship between forensic science and biometry.⁹⁸¹

The use of physical and chemical “extraction” and enhancement of latent prints is extensively covered in the “Fingerprint sourcebook”,⁹⁸² a publication by the National Institute of Justice, discussed in more detail later in paragraph 7.3 of this chapter.

Published literature and books support the validation and scientific foundation of reliable analytical methods that can be applied in the development and enhancement of latent print evidence found at crime scenes. Similar to Chemistry and DNA, some of these discoveries were first made outside the field of forensic science and later applied within the fingerprint evidence community.

The next step in the process of examination is the interpretation and drawing of inferences between the unknown developed (enhanced) print and known prints (ten prints) on record. Due to the fact that some unknown prints were only partial prints with limited amount of characteristics (ridge pattern, number of minutiae, and ridge pores/edges), a probability value or likelihood ratio was needed to support the value of the evidence. This required statistical models to support the question of variability of fingerprint evidence found on crime scenes.

⁹⁷⁸ Bergman H and Zeelenberg A “Fingerprint Matching, Manual” in *Encyclopedia of Biometrics* Li SZ and Jain A eds. (New York: Springer Verlag 2009) 502-509.

⁹⁷⁹ Busey TA and Schneider BL “Latent Fingerprint Experts” in *Encyclopedia of Biometrics* Li SZ and Jain A eds. (New York: Springer Verlag 2009).

⁹⁸⁰ Flynn PJ *et al.* *Handbook of Biometrics* (New York: Springer-Verlag 2007).

⁹⁸¹ Dessimoz D and Champod C “Linkages between Biometrics and Forensic Science” in *Handbook of Biometrics* Flynn PJ *et al.* eds. (New York: Springer-Verlag 2007) 425-459.

⁹⁸² US Department of Justice, National Institute of Justice “Fingerprint Sourcebook” 2005 Chapter 7 <https://www.ncjrs.gov/pdffiles1/nij/225320.pdf> (Date of use: 18 May 2018).

7.2.5 Introduction to statistical models, interpretation and error rates

7.2.5.1 Early match process models

The application of statistical models is not new to fingerprint evidence. Historically, Galton and Forgeot were the first to attempt and articulate a match process.⁹⁸³ Forgeot suggested using enlarged photographs of the two impressions while tracing ridge lines for enhancement. A comparison between the two traced photographs was then made and a conclusion derived. The Galton Model⁹⁸⁴ used minutia event probabilities to derive a Probability of Random Correspondence (PRC). Galton focused on a more systematic methodology by using level 1 detail on 1,000 thumb prints to calculate the probability of corresponding fingerprint pattern classification. The application of the model raised questions on the quantity of minutiae points⁹⁸⁵ required to make a match. The model did not propose an identification framework, but rather used a local ridge analysis.

Subsequent models based on Galton's square region ridge analysis were formulated by various researchers.^{986,987,988,989} These region-based methods relied on Galton's assumption that there is no correlation between the region characteristics and surrounding region characteristics.

Henry⁹⁹⁰ suggested a minutiae event-based mode that was based on modelling minutiae occurrences as independent random events, with no regional ridge analysis (such as square ridge

⁹⁸³ Cole SA *History of Fingerprint Pattern Recognition, Automatic Fingerprint Recognition Systems* Ratha N and Bolle R (New York: Springer Verlag 2004) 1-25.

⁹⁸⁴ Galton F *Finger Prints* 1892.

⁹⁸⁵ NIJ *Fingerprint Sourcebook* 2005 [6-24]. Local fingerprint ridge singularities, commonly known as minutiae points, have been traditionally used by forensic experts as discriminating features in fingerprint images. The most common local singularities are ridge endings and ridge bifurcations. Other types of minutiae mentioned in the literature, such as the lake, island, spur, crossover, and so forth (with the exception of dots), are simply composites of ridge endings and bifurcations.

⁹⁸⁶ Roxburgh T "On evidential value of fingerprints" 1934 *Sankhya: Indian J Stat* 1:189-214.

⁹⁸⁷ Amy L "Recherches sur l'identification des traces papillaires (Translated as "Research on the identification of papillary traces" 1948 *Annales de Médecine L'égalé* 28(2):96-101).

⁹⁸⁸ Kingston C *Probabilistic Analysis of Partial Fingerprint Patterns* (Ph.D thesis University of California 1964).

⁹⁸⁹ Osterburg J *et al.* "Development of a mathematical formula for the calculation of fingerprint probabilities based on individual characteristics" 1977 *Journal American Statistic Association* 72(360):772-778.

⁹⁹⁰ Henry "Classification and Uses of Finger Print" 1900.

region analysis based models) or spatial information used to model such minutiae event probabilities. He used minutiae information such as total number of minutiae and/or type that are the possible input parameters for the model to calculate PRC values. The model was the first one to consider minutiae as independent events, along with core-to-delta ridge count and classification weighting. He was later criticised for neglecting to empirically quantify the values suggested in his equation; the setting of these values was largely found to be arbitrary. No relevant empirical evidence backed the decision to choose the selected probability values.

In 1910, Dr. Victor Balthazard⁹⁹¹ attempted to establish a statistical basis for fingerprint use towards the accuracy of evidence interpretation and suggested what he believed to be a valid guideline for their identification. He provided a numerical standard and suggested a 17 corresponding minutiae in comparison matches with certainty. He also suggested that this number could be lower when the surrounding population of the town or country is smaller. Balthazard's work provided the basis for Locard's Tripartite Rule, referring to statistical models supporting quantifiable thresholds for friction ridge individualisation.

7.2.5.2 Tripartite Rule

In 1914, the French criminalist Edmond Locard (Champod, 1995)⁹⁹² made the earliest concise attempt to provide an identification framework, known as the Tripartite Rule, where the weight of evidence for identification is described as a continuous determination of the sufficiency of evidence for identification. The determination of sufficiency encompassed a probabilistic component for insufficient or inconclusive evidence, along with a numerical standard for evidence deemed sufficient for a conclusive identification. The Tripartite Rule was described as follows:

- Positive identification is possible with more than 12 minutiae if the fingerprints are sharp (i.e., high quality).⁹⁹³

⁹⁹¹ Balthazard V “De l’identification par les empreintes digitales” (Translated as “From identification by fingerprints”) 1911 *Comptes Rendus des S’eances de l’Academie des Sciences* 152:1862-1864.

⁹⁹² Champod C “Edmond Locard—Numerical standards and ‘probable’ identifications” 1995 *J Forensic Ident* 45:136–155.

⁹⁹³ Champod *Numerical standards* 1995 [137].

- If 8 to 12 concurring points are involved, then the case is borderline and the certainty of identity will depend on quality of prints, rarity of pattern, presence of core and deltas, presence of pores, width of the papillary ridges and valleys, and directions of minutiae and ridges in general. In these cases, certainty can only be established by at least two fingerprint experts.
- If a limited number of characteristic points are present, the fingerprints cannot provide certainty for an identification, but only a presumption that is proportional to the number of points available and their clarity (i.e., probabilistic value).

The tripartite rule proposes a framework for fingerprint identification that included all levels of detail. Taken in a holistic sense, the tripartite rule could be seen as a probabilistic framework, where the successful applications of the first and second rules were analogous to a 100 % probability that impressions were from the same sources, whereas the third rule covered the probability range of 0 % to 100 %.

Locard summarised the principles of identification into three classes:⁹⁹⁴

- where there were more than twelve evident points and the impression clear, identification absolute;
- where there were eight to twelve points, identity would depend upon
 - o clearness of the impression,
 - o rarity of the type,
 - o presence of the core or of the delta in the part that is decipherable,
 - o presence of pores,
 - o the perfect and evident identity of the breadth of the ridges and furrows, the direction of the lines, and the angular value of the furrows-in which case the certainty of identification was to be established only after discussion of the case was conducted by one or more competent experts;

⁹⁹⁴ Locard E *La Preuve Judiciaire par les Empreintes Digitales* (1914) as translated in bulletin issued on Nov. 1, 1932, by the Division of Investigation of the United States Department of Justice.

- where there were fewer points, the print, taken by itself, did not furnish positive identity, but only a presumption that is proportional to the number and clearness of the points. Should a number of prints of the 3rd level be available, their value was, of course, enhanced by their number.

Wilder and Wentworth⁹⁹⁵ indicated that the authorities Galton, Fere, Balthazard, Oloriz and others appear to show that positive identity can scarcely be claimed without at least twelve homologous points of comparison. However, the said authors expressed the opinion that six or eight points well-grouped, defining a center of exceptional form, would constitute such perfect proof of identity as to give no grounds for argument.⁹⁹⁶

7.2.5.3 Statistical variations between prints

The same authors⁹⁹⁷ were also the first to explore statistical variations between prints. They selected two ulnar loops from the right middle fingers of two individuals in their database; a type that occurs with the greatest frequency (3,719 out of 5,000). In their view, the separation of these two prints presented the most difficult case possible for the “ordinary” or “practical”. At the natural size, the two prints may look very much alike, but at a 4 times magnification, start to show slight differences (ridge count between delta and core were 18 and 15 respectively). They then pursued a higher magnification and pointed out various dissimilarities on the minutiae, as well as pores on the ridges. Their conclusion was that in instances where a complete single fingerprint impression found at a crime scene is considered identical with the known sample obtained from a suspect, the mathematical probability of error of two different individuals making exactly the same print, would be approximately one in sixty-four billion.

⁹⁹⁵ Wilder and Wentworth *Identification of individuals* 1918.

⁹⁹⁶ Division of Investigation of the United States Department of Justice 13. Bulletin issued on 1932-11-01.

⁹⁹⁷ Wilder and Wentworth *Identification of individuals* 1918.

7.2.5.4 Numerical lower limit rule

It was Locard's first rule of imposing a numerical lower limit for a positive identification became the standard practice for many jurisdictions worldwide, and is still used to some extent in conjunction with the ACE-V framework (i.e., for the evaluation stage). European practitioners still prefer a quantitative approach,⁹⁹⁸ prescribing a fixed numerical standard. For example, Belgium, Finland, France, Greece, Ireland, Israel, Poland, Portugal, Romania, Slovenia, Spain, Turkey, Japan, and countries within the South Americas, are examples of jurisdictions that adhere to the 12-point rule. Other jurisdictions employ rules based on combinations of Locard's first and second rules (for example, Germany, Sweden, Holland, and Switzerland).

Italy adopted a 16-17 point rule prescribed in the studies of Balthazard, and in the United Kingdom a 16-point rule was selected in 1924, based on the Alphonse Bertillon's published article where he constructed two different fingerprints from fragments of other fingerprints, resulting in both artificial fingerprints loosely having 16 minutiae in agreement.⁹⁹⁹ Since 2001, the United Kingdom has adopted a non-numeric holistic approach.

In 1934, Fred Inbau¹⁰⁰⁰ stated that for statistical precision, it would be necessary to compare every fingerprint in the world with every other print, and such research would be impractical and impossible. The only thing examiners could depend on was the assurance as to the accuracy of fingerprint identification, based on the fact that:

- no two separate fingerprints have ever been located which were identical in all respects- not even in cases of identical twins, and
- conservative mathematical calculations indicated the extreme improbability of an extraneous duplication.

⁹⁹⁸ Champod C *et al.* *Fingerprints and Other Ridge Skin Impressions* (2nd ed CRC Press Boca Raton 2016).

⁹⁹⁹ Cole SA "What Counts for Identity? The Historical Origins of the Methodology of Latent Fingerprint Identification" 1999 *Sci in Context* 12(1):139-172.

¹⁰⁰⁰ Inbau FE "Scientific Evidence in Criminal Cases" 1934 *J of Crim Law and Criminology* 25(3):379-391.

7.2.5.5 Probability of Random Correspondence (PRC)

Roxburg¹⁰⁰¹ introduced the first Landmark referencing model which utilised key landmark features, such as well-defined minutiae or a core as a spatial reference for other additional surrounding features, which contributed to the computation of PRC values. Examples of landmark referencing models include Roxburgh (1934), Trauring (1963), and Stoney (1985).

After 1950, researchers continued with attempts to answer the question regarding the scientific reasoning of a numerical standard. Additional research studies were conducted by Kingston (1964)¹⁰⁰² and Osterburg *et al.* (1977)¹⁰⁰³ on square ridge analysis-based model variants. Kingston¹⁰⁰⁴ also recommended changes to the minutiae even-based model of Henry, by combining probability calculations for a given configuration of minutiae from pre-established values for expected minutiae density and type frequencies. A shortcoming of the Kingston model was the assumption of minutiae type probability being independent of its special region. The orientations of minutiae were not considered in the probability calculations. Trauring (1963)¹⁰⁰⁵ and Stoney (1985)¹⁰⁰⁶ continued research on landmark referencing models. Trauring focused on the analysis of correspondences found in a theoretical automatic fingerprint identification system (AFIS). The Trauring model lacked a strong empirical foundation for the estimated values of p (probability of finding an acceptable set of corresponding reference minutiae) and d (the average minutia density for a region of area $7.068r^2$), as it relied on a very small sample set and the incorrect assumptions made regarding uniform minutiae density and type frequencies.¹⁰⁰⁷ The Stoney model suggested models that are primarily based on ridge structure and minutiae location to properly model the PRC of fingerprints. Again, assumptions of independence between orientation and location, and

¹⁰⁰¹ Roxburgh On evidential value 1934. Roxburgh's model created minutia code based on a polar coordinate system to uniquely identify minutiae. A minutia order was defined by creating a configuration of concentric circles spaced with one ridge intervals from the core (or other well defined landmarks), and moving clockwise from the vertical axis noting the ridge count (or concentric circle number) from the origin, along with minutiae types earlier defined by Balthazard (1911) (i.e., left/right bifurcations ridge endings).

¹⁰⁰² Kingston Probabilistic Analysis 1964.

¹⁰⁰³ Osterburg Development of a mathematical formula 1977.

¹⁰⁰⁴ Kingston Probability analysis 1964.

¹⁰⁰⁵ Trauring M "Automatic comparison of finger-ridge patterns" 1963 *Nature* 197;871: 938-940.

¹⁰⁰⁶ Stoney DA "A Quantitative Assessment of Fingerprint" (Individuality, D. Crim. Dissertation, Graduate Division of the University of California: University of California Berkeley 1985).

¹⁰⁰⁷ Trauring M *Comparison* Nature 1985 [938].

inaccurate and over-conservative orientation probability calculations, led to model deficiencies. The statistics were also centered on focal minutiae above the core location, and were not randomly selected from all parts of the fingerprint region.¹⁰⁰⁸

In the beginning of the 21st century, PRC models were more AFIS-centric, containing a large dataset of fingerprint impressions, combined with automation of within and between finger feature searching. This allowed for data-driven statistical frameworks which can be tested for accuracy in evaluations. Pankanti *et al.*¹⁰⁰⁹ made the first proposition on a spatial homogeneity model, which was based on rudimentary principles of minutiae-matching algorithms in an AFIS-centric model. This was followed by Chen and Moon¹⁰¹⁰ in 2007, who proposed a model based on that of Pankanti, but minutiae-pairing directional differences of imposters were also modelled and assumed not uniform. They also assumed spatial patterns of minutiae to have complete spatial randomness. The experimental results showed that the simulated distribution of the model was closer to the observed empirical distributions.

7.2.5.6 Spatio-directional generative model

In 2005, Dass *et al.*¹⁰¹¹ proposed the first spatio-directional generative model, which modelled general minutiae location and direction dependencies by using a number of finite continuous distribution-based mixture models. Their experiment showed results that were even closer to the empirical PRC values that were generated from matching the Dass algorithm than if matched with the Pankanti model.

The spatio-directional feature model of Dass was extended by Su and Srihari¹⁰¹² in 2010, by including neighboring inter-minutiae dependencies using Bayesian networks that were based on

¹⁰⁰⁸ Stoney DA "Assessment Dissertation".

¹⁰⁰⁹ Pankanti S *et al.* "On the individuality of Fingerprints" 2001 *in Proc Conf Computer Vision and Pattern Recognition* 805-812.

¹⁰¹⁰ Chen J and Moon YS "A Minutiae-based Fingerprint Individual Model" 2007 *in Proc Computer Vision and Pattern Recognition CVPR '07 IEEE Conference* 1-7.

¹⁰¹¹ Dass SC *et al.* "Statistical Models for Assessing the Individuality of Fingerprints" 2005 *in Proc Workshop on Automatic Identification Advanced Technologies* 3-9.

¹⁰¹² Su C and Srihari SN "Evaluation of Rarity of Fingerprints in Forensics" In (Lafferty J, *et al.* eds 2010 *Advances in Neural Information Processing Systems*) 23:1207-1215.

a defined minutiae sequence. Bayesian networks present a powerful statistical modelling technique that represents a set of random variables and their conditional dependencies (i.e., statistical relationships) using directed acyclic graphs. They were also used in evaluating DNA profiling evidence.¹⁰¹³

7.2.5.7 Likelihood Ratio (LR) Models

Besides PRC model development, other researchers conducted further research on likelihood ratio (LR) models. It was a simple and powerful statistical tool used in forensic science applications, and provided the ratio of two likelihoods of a specific event occurring, each with its own hypothesis, and thus having an empirical distribution. Neumann *et al.*¹⁰¹⁴ (2006) created a feature vector-based likelihood ratio model constructed from the Delaunay triangulation¹⁰¹⁵ of selected minutiae. The year thereafter he discovered a challenge with the proposed feature vector structure's robustness when distortion of minutiae points occurred, and subsequently published a follow-up paper¹⁰¹⁶ in which an increased number of minutiae in the structures was suggested. He noticed within- and between-finger variability that was both robust and accurate with more minutiae added. In 2012, Neumann¹⁰¹⁷ proposed another model, which further refined using distortion and examiner influence models, leading to a modified version of what Neumann and colleagues published in 2015,¹⁰¹⁸ which incorporates a measure of "sufficiency similar" to the LR calculation.

¹⁰¹³ Biedermann A and Taroni F "Bayesian networks for evaluating forensic DNA profiling evidence: a review and guide to literature" 2012 *For Sci Int Gen* 6(2):147-57.

¹⁰¹⁴ Neumann C *et al.* "A Computation of Likelihood Ratios in Fingerprint Identification for Configurations of Three Minutiae" 2006 *J Forensic Sci* 51(6):1255-1266.

¹⁰¹⁵ Delaunay B "Sur la sphère vide" 1934 *Bulletin de l'Académie des Sciences de l'URSS, Classe des Sciences Mathématiques et Naturelles*. 6:793–800. In mathematics and computational geometry, a Delaunay triangulation (also known as a Delone triangulation) for a given set P of discrete points in a plane is a triangulation DT(P) such that no point in P is inside the circumcircle of any triangle in DT(P). Delaunay triangulations maximize the minimum angle of all the angles of the triangles in the triangulation; they tend to avoid sliver triangles. The triangulation is named after Boris Delaunay for his work on this topic from 1934.

¹⁰¹⁶ Neumann C *et al.* "A Computation of likelihood ratios in fingerprint identification for configurations of any number of minutiae" 2007 *J Forensic Sci* 52(1):54-64.

¹⁰¹⁷ Neumann C "Statistics and Probabilities as a Means to Support Fingerprint Examination" Chapter 15 *Advances in Fingerprint Technology* (3rd ed. Ramotowski RS CRC Press 2012) 419-452.

¹⁰¹⁸ Neumann C *et al.* "Quantifying the weight of fingerprint evidence through the spatial relationship, directions and types of minutiae observed on fingermarks" 2015 *Forensic Sci Int* 248:154-171.

Egli *et al.*¹⁰¹⁹ used an AFIS score based LR model to derive an LR by using estimates of the genuine and imposter similarity score distributions from fingerprint matching algorithms. This was followed by another paper¹⁰²⁰ that proposed the use of the Weibull $W(\lambda, \beta)$ and Log-Normal $\ln \mathcal{N}(\mu, \sigma^2)$ distributions, with scale/shape parameters tuned to estimate the genuine and imposter AFIS score distributions respectively.

7.2.5.8 Error rate determination

One important legal point still unaddressed, was the question on error rates within the fingerprint community and the search for ways to determine those error rates, an issue which had started receiving attention the late 20th century. The question to answer regarding error rates, was whether different examiners will come to the same conclusion when comparing two prints (unknown to known). This is better described by the principle of how many false positives or false negatives will exist when a number of examiners look at the same set of fingerprints. The value is important for the criminal justice system, because it provides scientific validity to the methodology used to form an opinion.

In 1995, Evert and Williams¹⁰²¹ reviewed fingerprint conclusions based on 16-point standard used in the United Kingdom. They used 130 fingerprint examiners from bureaus in England and Wales with more than ten years of experience to independently compare ten latent impressions with known standards. This study showed that the examiners made zero false positive decisions and ten false negative decisions.

¹⁰¹⁹ Egli NM *et al.* "Evidence evaluation in fingerprint comparison and automated fingerprint identification systems—modelling within finger variability" 2007 *Forensic Sci Int* 167(2-3):189-195.

¹⁰²⁰ Egli NM Interpretation of Partial Fingermarks Using an Automated Fingerprint Identification System (Ph.D. Thesis Faculty of Law and Criminal Justice University of Lausanne 2009).

¹⁰²¹ Evert I and Williams R "A Review of the Sixteen Points Fingerprint Standard in England and Wales" In: *Proceedings of the International Symposium of Fingerprint Detection and Identifications* Almog J and Spinger E (Ne'urim Israel 1995) 287-304.

After studying the results of fingerprint experts over a period of six years in Australia, Gutowski published his findings on error rates in fingerprint examinations in 2006.¹⁰²² He reported that of the 782 decisions of examiners, no erroneous individualisations or exclusions were detected, but two transcription errors were noted and documented. All examiners applied the ACE-V methodology during their decision making process.

In 2011, after a call for research on the accuracy and reliability of latent print examiners' decisions, Ulery *et al.* published the results of their study in a paper, titled "Accuracy and reliability of forensic latent fingerprint decisions."¹⁰²³ The study was based on empirical approaches to solve the problem. They used 169 latent examiners, who each compared 100 pairs of latent and exemplar fingerprints from a pool of 744 pairs. This study resulted in 17,121 decisions made by examiners. The results indicated a 0.1 % false positive error rate and a 7.5 % false negative error rate. On blind verification by independent examiners, all false positives and a majority of false negative errors were detected. The results of the study were well received from those working within the discipline, who used the results in trial to display the error rate in decision making by trained and experienced examiners. This was known as the first comprehensive "black box study". The black box study is an approach where stimuli of known ground truths are provided to an instrument—here the fingerprint analyst—and the output is examined and compared against the expected answer. In this way, the analyst is treated as a black box, where what occurs inside the box remains largely unknown, and is not considered relevant to studying the resulting output.

Champod *et al.* (2016)¹⁰²⁴ acknowledged the significant improvements in AFIS software algorithms, which would lead to the automation of easy identification decisions, while databases will continue to grow and become more interconnected. Similar to DNA mixtures of low quantity, true matches with low quality and distorted prints with some similarity can lead to more erroneous identification decisions.

¹⁰²² Gutowski S "Error rates in fingerprint examination: The view in 2006" *The Forensic Bulletin*, (autumn 2006) 18-19.

¹⁰²³ Bradford T *et al.* "Accuracy and reliability of forensic latent fingerprint decisions" 10 May 2011 *PNAS* vol 108 no 19: 7733–7738. www.pnas.org/cgi/doi/10.1073/pnas.1018707108 (Date of use: 03 January 2019).

¹⁰²⁴ Champod "Fingerprints" 2016.

Other publications of interest for the purpose of this study are the work of Champod¹⁰²⁵ on “Identification and Individualization”; Aitken’s¹⁰²⁶ analysis of different probabilistic tools used in forensic science, including errors (e.g. prosecutor’s fallacy); Koehler’s¹⁰²⁷ discussion on the presentation and understanding of evidence in the courtroom, as well as the study by Moenssens¹⁰²⁸ on demonstrative forensic evidence and the necessity that the probative effect outweighs the prejudicial impact for the evidence to be admissible.

The NAS report, discussed later in this chapter, cautioned that not enough attention had been given to error rates in the discipline relating to the determination of false positive and false negative error values. One way to address that shortcoming is to use “black box” or “white box” studies, which will be addressed under the NAS and PCAST report section in this chapter.

Although various approaches were used to compare, interpret data and deliver opinions, the discipline needed standardisation. Standardisation in the form of an analytical approach or analytical scheme, is used when comparing an unknown print with a known print. The second form of standardisation refers to the need for a governing body of experts to provide guidance within the discipline. The next two sections will cover ACE-V methodology (abbreviated from Analysis, Comparison, Evaluation and Verification) as an established standard approach to fingerprint evidence analysis, and the establishment of standardising bodies to provide guidance in the fingerprint discipline.

¹⁰²⁵ Champod C “Identification and Individualization” in Wiley *Encyclopedia of Forensic Science* vol 3 Jamieson A and Moenssens A (Chichester UK: Wiley 2009) 1508-1511.

¹⁰²⁶ Aitken CGG “Interpreting Expert Opinions: History of”. In Wiley *Encyclopedia of Forensic Science* vol 3 Jamieson A and Moenssens A (Chichester UK: Wiley 2009) 1579-1586.

¹⁰²⁷ Koehler JJ “Statistical Evidence in Court” in Wiley *Encyclopedia of Forensic Science* vol 5 Jamieson A and Moenssens A (Chichester UK: Wiley 2009) 2401-2409.

¹⁰²⁸ Moenssens A “Demonstrative Evidence” in Wiley *Encyclopedia of Forensic Science* vol 2 Jamieson A and Moenssens A (Chichester UK: Wiley 2009) 745-747.

7.2.6 Introduction to ACE-V methodology

Practitioners used various methods in reaching conclusions and ultimately to form their opinions. There were various paths to reach a decision, but none of them formalised a method of analysis. Although Heindl¹⁰²⁹ and Locard¹⁰³⁰ clearly envisioned a standardised method for the examination of fingerprint evidence, it was Roy Huber, an Assistant Commissioner and document examiner, from the Royal Canadian Mounted Police (RCMP), who first articulated the term Law of ACE or ACE methodology^{1031,1032,1033} in 1959, which later became ACE-V.¹⁰³⁴ In 1972, Huber stated that the purpose for development of the ACE methodology was to develop a method that would be considered scientific in nature.¹⁰³⁵ He was credited with defining this approach as a way to compare two things, regardless of subject matter, and to identify if the two items have a correlating relationship. The method followed essential components of the scientific method, which included asking a question, forming a hypothesis, testing the hypothesis, analysing the data, and drawing conclusions. Huber's methodology always began with forming the same question regarding whether or not the two items of comparison shared a common relationship. The analysis phase was assigned to observe comprehensively the quality, uniqueness, and varying characteristics that the object (such as a fingerprint) contained.¹⁰³⁶ The next phase was to test the hypothesis by comparing the two items of study to one another and determine whether the second item shared similar unique characteristics with the first item.¹⁰³⁷ The last phase was for the examiner to evaluate the two items and to determine whether they shared a relationship and came from the same source.¹⁰³⁸ However, Vanderkolk¹⁰³⁹ and Speckels¹⁰⁴⁰ asserted that Huber missed one step in

¹⁰²⁹ Heindl R "System und Praxis der Daktiloskopie" (Berlin und Leipzig: Walter de Gruyter & Co Vereinigung Wissenschaftlichen Verleger 3rd ed 1927).

¹⁰³⁰ Locard E "Traité de criminalistique Vol.I à VII" (Lyon: Joannès Desvigne et fils éditeurs 1931).

¹⁰³¹ Huber RA "Expert witness" 1959 *The Criminal Law Quarterly* 2(3):276-295.

¹⁰³² Huber RA "The philosophy of identification" *RCMP Gazette* (1972) July-August 9-14.

¹⁰³³ Huber RA and Headrick AM *Handwriting Identification: Facts and Fundamentals* (Boca Raton: CRC Press 1999).

¹⁰³⁴ Triplett M and Cooney L "The etiology of ACE-V and its proper use: An exploration of the relationship between ACE-V and the scientific method of hypothesis testing" 2006 *J Forensic Ident* 56(3):345-355.

¹⁰³⁵ Huber "Identification" 1972.

¹⁰³⁶ Speckels C "Can ACE-V Be Validated?" 2011 *J Forensic Ident* 61:201-209.

¹⁰³⁷ Vanderkolk JR "ACE+V: A Model" January 2004 *J Forensic Ident* 54(1):45-52.

¹⁰³⁸ Speckels "ACE-V Validation" 2011.

¹⁰³⁹ Vanderkolk "ACE+V: A Model" 2004

¹⁰⁴⁰ Speckels "ACE-V Validation" 2011.

the scientific method: the verification, or testing of the original hypothesis. It was only twenty years later in 1979, that David Ashbaugh added verification to the ACE methodology.¹⁰⁴¹ At the time, Asbaugh believed it would complete the scientific method.¹⁰⁴² He stated that “*verification is a form of peer review and is part of most sciences [...] its purpose is to verify the process and objectivity as opposed to only checking results.*” (emphasis added).¹⁰⁴³

The new acronym ACE-V became the new way of thinking for latent print examiners conducting friction ridge examinations. It was believed that the method provided a more objective directive tool when comparing friction ridge impressions. It became an applied scientific method that relies on both interpretation and judgment.¹⁰⁴⁴ Although introduced by Asbaugh in 1991, the method only gained widespread acknowledgement in 1999 in the case of *U.S v. Mitchell* (discussed later in this chapter). A comprehensive layout of the ACE-V was reported in the dissertation study of Langenburg.¹⁰⁴⁵

The ACE-V method did not change the way practitioners did fingerprint examinations, but it changed the way they articulate the process. The ACE-V process also allowed for more descriptive phases of the examination process, for example how an examiner communicates compared fingerprints.

Ashbaugh described three levels of information by describing features visible in the deposition mark without any a *priori* assessment of the selectivity of the features.¹⁰⁴⁶ During the analysis phase, it was expected that the practitioner would categorise all the features that were visible in the developed latent print, with an assessment of their reality and the deposition conditions. Clear

¹⁰⁴¹ Ashbaugh DR “Ridgeology” 1991 *J Forensic Ident* 41(1):16-64.

¹⁰⁴² Ashbaugh “Qualitative-Quantitative Friction Ridge Analysis” 1999.

¹⁰⁴³ Ashbaugh “Qualitative-Quantitative Friction Ridge Analysis” 1999.

¹⁰⁴⁴ Speckels *ACE-V Validation* 2011

¹⁰⁴⁵ Langenburg GM “*A critical analysis of study of the ACE-V process*” (Thesis for the Doctorate in Forensic Science University of Lausanne 2012).

¹⁰⁴⁶ Ashbaugh “Qualitative-Quantitative Friction Ridge Analysis” 1999. *Level 1* refers to the overall pattern formed by the flow of papillary ridges on the papillary surface. Traditionally, the general pattern formed on the fingertips has been classified into generic classes. *Level 2* refers to major ridge path deviations, also known as minutiae, points of identification, or Galton characteristics. Basic forms are ridge endings, bifurcations, and dots. *Level 3* refers to intrinsic or innate ridge formations: the alignment and shape of each ridge unit, pore shape, and relative pore positions.

annotations had to be added to the print, but many practitioners saw it as a time-consuming process and postponed the process until the comparison phase.¹⁰⁴⁷ The scientific basis of the ACE-V standardised method/procedure later gained prominence in trials and criticism regarding its validity and reliability started to emerge.

Not everyone in the scientific community was convinced by the ACE-V method. It was challenged by Clark,¹⁰⁴⁸ but defended by Vanderkolk¹⁰⁴⁹ and Wertheim,¹⁰⁵⁰ while Langenburg¹⁰⁵¹ redefined the analysis phase of the ACE-V process. Beeton¹⁰⁵² described a five-step process consisting of examination of the latent, development of hypotheses to be addressed, experimentation, formation of a tentative conclusion, and testing of the conclusion. He was strongly criticised by Busey and Vanderkolk,¹⁰⁵³ based on the differences between experienced practitioners who received proper training in fingerprint comparison and performed analyses for a period of time, versus novices that lacked both training and experience.

A number of important scholarly articles addressed the validity of fingerprint comparisons and ACE-V. It is important for the purpose of this study to reflect on some of these. Koehler¹⁰⁵⁴ discussed the validity (interpreted as both validity and reliability here) of the ACE-V method. He proposed that practitioners carry out testing for validity of the ACE-V method. Haber and Haber,¹⁰⁵⁵ however, argued that ACE-V is just a protocol, commonly used by practitioners, but that it does not ensure reliability. They further considered the usefulness of statistical models, specifying the selectivity of fingerprint features, as well as a call for transparency including the spelling out of the

¹⁰⁴⁷ Champod "Fingerprints" 2004.

¹⁰⁴⁸ Clark JD "ACE-V: Is it Scientifically Reliable and Accurate?" 2002 *J Forensic Ident* 52(4):401-408.

¹⁰⁴⁹ Vanderkolk JR "ACE+V: A Model" 2004 *J Forensic Ident* 54(1):45-51.

¹⁰⁵⁰ Wertheim K "Letter - re: ACE-V: Is it Scientific Reliable and Accurate?" 2002 *J Forensic Ident* 52(6) 669-677.

¹⁰⁵¹ Langenburg G "Pilot Study: A Statistical Analysis of the ACE-V Methodology -Analysis Stage" 2004 *J Forensic Ident* 54(1):64-79.

¹⁰⁵² Beeton M "Scientific Methodology and the Friction Ridge Identification Process" 2002 *Ident Canada* 25(3):4-8.

¹⁰⁵³ Busey TA and Vanderkolk JR "Behavioral and Electrophysiological Evidence for Configural Processing in Fingerprint Experts" 2005 *Vis Res* 45:431-448.

¹⁰⁵⁴ Koehler JJ "A Welcome Exchange on the Scientific Status of Fingerprinting" 2008 *Law Probab Risk* 7:85-86.

¹⁰⁵⁵ Haber L and Haber RN "Scientific Validation of Fingerprint Evidence under Daubert" 2008 *Law Probab Risk* 7:87-109.

ACE-V protocol. Their criticism was echoed by Cole,¹⁰⁵⁶ who also denied the ACE-V the status of a methodology. Cole pointed out the irrelevance and soundlessness of the science behind the approach and called for proper validation to determine its reliability.

Reznicek¹⁰⁵⁷ *et al.* integrated ACE-V into a 7-step scientific method. These steps included:

- observation
- stating of the question
- generation of a hypothesis
- conducting experiments (analyses and comparison)
- formulation of conclusions (evaluation)
- replication (verification), and
- reporting.

The authors proposed a consideration that the premises of fingerprint individualisation (persistence, unicity and classifiability) are theoretical. They maintained that the hypotheses, to date, have not been falsified through testing and therefore, being supported by evidence, have gained the status of theory. Langenburg¹⁰⁵⁸ performed a pilot study applying the ACE-V process to measure the accuracy, precision, reproducibility, repeatability and biasness of conclusions. In the study of 720 comparisons, three erroneous identifications were made - two did not complete a verification and the third was resubmitted to the same analyst who did not repeat the error. Divergences appeared between definitive exclusions (identification/exclusion) and inconclusive / no value conclusions.

The ACE-V method has since been adopted internationally in many forensic crime laboratories and law enforcement entities as a procedural method when working with fingerprint evidence. The ACE-V method was challenged in many court hearings for validity and reliability and will be

¹⁰⁵⁶ Cole SA "Comment on scientific Validation of Fingerprint Evidence under Daubert" *2008 Law Probab Risk* 7:119-126.

¹⁰⁵⁷ Reznicek M *et al.* "ACE-V and the Scientific Method" *2010 J Forensic Ident* 60:87-103.

¹⁰⁵⁸ Langenburg G "A Performance Study of the ACE-V Process: A Pilot Study to Measure the Accuracy, Precision, Reproducibility, Repeatability, and Biasability of Conclusions Resulting from the ACE-V Process" *2009 J Forensic Ident* 59:219-255.

discussed in the section where the law challenged the scientific method. Besides adopting the ACE-V methodology within the fingerprint discipline, there was and still is a need for uniformity. The next section will discuss how entities were established to support uniformity within the discipline through standardisation.

7.3 Standadisation

7.3.1 *International Association of Identification*

The need for standardisation arose as early as October, 1915, with the establishment of the “International Association for Criminal Identification” and would later be renamed “International Association for Identification” (IAI) in 1918.¹⁰⁵⁹ Their mission was to strive to become the primary professional association for those engaged in forensic identification, investigation, and scientific examination of physical evidence. Their level of influence grew, and in 1921, members who attended the conference were received by President Harding in the White House, where he handed his own personal fingerprints to the group, in support of the work of the organisation.

At the International Police Conference held in New York, in 1925, a committee was appointed to devise a new universal fingerprint system for use throughout the world. It was the first attempt to construct such a system for international use.¹⁰⁶⁰

By 1929, the IAI formed various sub-committees to provide technical assistance to its members in practice.¹⁰⁶¹ It also had regional representatives in most states of the United States, as well as in Canada, China, Cuba, Mexico, and the Philippines.

With the great depression and World War II, the IAI went silent in the early 1930s and re-established their activities in the late 1960s and early 1970s. With the growing crime rates among those fighting crime, a renewed need for standardisation and automation became apparent. A

¹⁰⁵⁹ International Association for Identification (IAI) “History”. http://www.theiai.org/iai_history.php (Date of use: 28 December 2018).

¹⁰⁶⁰ Fingerprint and Identification *Magazine* 24:1942 [28].

¹⁰⁶¹ IAI History 1929. http://www.theiai.org/iai_history.php (Date of use: 28 December 2018).

resolution was adopted in 1970, at the 55th Annual Educational Conference of the IAI in Pittsburgh, PA, to create the Standardisation Committee. The original fingerprint committee consisted of eleven experienced examiners and were tasked with two goals:

- To determine the minimum number of friction ridge characteristics which must be present in two impressions in order to establish positive identification, and
- To recommend the minimum requirements of training and experience which a person must possess in order to be considered qualified to give testimony on friction ridge impressions before a grand jury or court of law.¹⁰⁶²

After three years of extended studies and research, the committee stated that “no valid basis exists at the time for requiring that a predetermined minimum number of friction ridge characteristics must be present in two impressions in order to establish positive identification.”¹⁰⁶³ This was in contradiction with policies of many agencies around the globe, but the IAI took a position on this issue. In the mid-1970s, discussions arose on this contradictory statement and practice, especially regarding expert witness testimony on providing opinions when insufficient friction ridge detail did not exist. At the 64th IAI annual conference in Phoenix, Arizona in 1979, a strong statement was made to members in the fingerprint community in the form of Resolution VII, to avoid testimony or the reporting of “*possible*”, “*probable*” or “*likely*” friction ridge identification. These resolutions became the impetus for additional research on processes by which examiners should analyse, compare and identify fingerprint evidence.

In 1964, Osterburg and Bloomington explored the judgements of fingerprint examiners for the first time and reported fingerprint examiner variability.¹⁰⁶⁴ They included 82 fingerprint examiners in a survey and determined that there was no universally accepted minimum threshold number of minutiae necessary to establish a positive identification. Other authors would later describe it as a

¹⁰⁶² International Association for Identification “*Identification News*” August 1973.

¹⁰⁶³ IAI Identification News 1973.

¹⁰⁶⁴ Osterburg JW and Bloomington SA “An inquiry into the nature of proof: The Identity of Fingerprints” 1964 *J Forensic Sci* 9(4):413-427.

“holistic” approach,^{1065,1066} as they considered the bigger picture and various factors before making a decision.

In 1985, the FBI’s book, titled, “The Science of Fingerprints: Classification and Uses”,¹⁰⁶⁷ appeared. It was directed toward law enforcement officers and agencies working with fingerprint identification and discussed pattern interpretation in detail to assist practitioners in decision making processes. In the introduction it is stated that “[o]f all the methods of identification, fingerprinting alone has proved to be both infallible and feasible”. This statement became a key topic for critics on how to prove a method falsifiable if it is infallible (perfect without error). The FBI did not refer to comparisons of an unknown latent to known prints when they published this statement, but by comparing fingerprint sets of individuals against each other. Of all the millions of prints they had historically collected, no two sets of prints showed any similarity. It was still a strong statement to make as nothing is perfect without error.

During October 1989, historical meetings took place in England regarding suggested changes to the fingerprint service in England and Wales, under the auspices of the Association of Chief Police office.¹⁰⁶⁸ Fingerprint practitioners were given the opportunity to discuss the abolishment of the 16-point identification system, and moved to a *no standard system* as applied by the United States and Canada at the time. Dr. Evett presented at the meeting the argument that the criterion followed by the US and Canada practitioners, when testifying on identification of fingerprints without a 16-point system, was viable and allowed for more cases to be presented in courtrooms.

The second point of interest was that the establishment of a fingerprint training school to standardise training and monitor practitioner’s efficiency, was recommended. It was decided to keep the 16-point standard at the time. However, at the 2001 National Fingerprint conference,

¹⁰⁶⁵ Vanderkolk JR *Forensic Comparative Science: Qualitative Quantitative Source Determination of Unique Impressions, Images, and Objects* (Burlington MA: Elsevier Academic Press 2009).

¹⁰⁶⁶ Polski J et al. “The Report of the International Association for Identification, Standardization II Committee” 2010.

¹⁰⁶⁷ Federal Bureau of Investigation “*The science of fingerprints: classification and uses*” 1985. <https://babel.hathitrust.org/cgi/pt?id=mdp.39015041834824;view=1up;seq=14;size=75> (Date of use: 9 March 2019).

¹⁰⁶⁸ Ritchie AT “An Update on Some Recent Manchester Cases” 2002 *Fingerprint World* 28(107):11-17.

more than a decade after the former conference, a non-numeric standard was adopted in the UK and Wales.¹⁰⁶⁹

At the international symposium on fingerprint detection and identification in Ne'urim, Israel, in June 1995, the 1973 position statement was changed to read as follows: "No scientific basis exists for requiring that a pre-determined minimum number of friction ridge features be present in two impressions in order to establish a positive identification".¹⁰⁷⁰ The word "*valid*" was replaced by "*scientific*", taking in consideration the countries where a minimum number of Level II details are captured in written policies or legal decisions. A second change was to replace the word "*characteristics*" with the word "*features*", to allow for the use of all available friction ridge detail from level 1, level 2, and level 3. This would allow for the inclusion of creases, ridge edges, pores, etc. This became known as the "Ne'urim Declaration" and are to date still used by the majority of the forensic science community.¹⁰⁷¹

7.3.2 *Scientific Working Group on Friction Ridge Analysis, Study and Technology (SWGFAST)*

To continue with the process of standardisation and with the development of the field of fingerprint analysis, the Federal Bureau of Investigation (FBI) implemented a technical working group to develop best-practice guidelines for the community. In 1992, having witnessed the success of the program, they explored the concept of promoting the development of additional Technical Working Groups (TWGs) in support of other forensic disciplines. On June 10, 1995, a group of 15 recognised experts came together at the first meeting of what became known as the Technical Working Group on the Forensic Aspects of Friction Ridge Analysis.

The basic proposed purpose of the group, as captured in the minutes of the first meeting, was to:

- Create guidelines for latent print practitioner knowledge, analytical methodology, and ability to perform friction ridge examinations.
- Establish and promulgate methods for research and validation of innovative techniques.

¹⁰⁶⁹ Ritchie Update, Fingerprint World 2002.

¹⁰⁷⁰ Israel National Police "Proceedings of the International Symposium on Fingerprint Detection and Identification" 1995-06-26 to 30 Ne'urim, Israel.

¹⁰⁷¹ Polski J "Report of the IAI" March 2011.

- Propose that the guidelines be recognised by forensic administrators and the judicial arena as the standard for acceptable practices of friction ridge examinations.¹⁰⁷²

The FBI determined that the established TWGs were to become long-term functioning bodies and they were re-established as scientific working groups. The name, Scientific Working Group on Friction Ridge Analysis, Study and Technology (SWGFAST), was officially adopted in 1998.

As the role of SWGFAST evolved, its objectives became more refined and were more accurately reflected by the following:

- To establish standards and guidelines for the development and enhancement of friction ridge examiners' knowledge, skills, and abilities.
- To discuss and share friction ridge examination methods and protocols.
- To encourage and evaluate research and innovative technology related to friction ridge examination.
- To establish and disseminate standards and guidelines for quality assurance and quality control.
- To cooperate with other national and international organizations in developing standards.
- To disseminate SWGFAST studies, standards, guidelines, and findings.¹⁰⁷³

A similar statement was adopted by SWGFAST based on the 1973 IAI resolution:

“There is no scientific basis for requiring that a predetermined number of corresponding friction ridge details be present in two impressions in order to effect individualization.”¹⁰⁷⁴

¹⁰⁷² Scientific Working Group on Friction Ridge Analysis, Study and Technology (SWGFAST) 2002 *J Forensic Ident* 52(3):263-348.

¹⁰⁷³ SWGFAST https://www.biometrie-online.net/images/stories/dossiers/technique/empreintes/swgfast_april_2001.pdf (Date of use: 18 September 2018).

¹⁰⁷⁴ SWGFAST Standards for Conclusions 1.2.1 (2003).

SWGFAST also stated that “[f]riction ridge identifications are absolute conclusions. Probable, possible, or likely identification are outside the acceptable limits of the science of friction ridge identification”. Champod and Evett¹⁰⁷⁵ believe the statement illustrates the tension between probability and positivity. There were two matters of concern in the statement, namely: (1) is a statement of an absolute conclusion compatible with scientific reasoning? and, (2) is the denial of probabilistic reasoning compatible with a scientific pursuit? Champod and Evett explain the difference between deductive and inductive reasoning in the forensic context, and argue that transparency rather than obscurity is desirable when presenting opinions. Their views were countered by some practitioners^{1076,1077} who continued using positivity as a set of principles laid down by an authority as incontrovertibly true.

In 2002, SWGFAST released a document for the application of ACE-V titled “Friction Ridge Examination Methodology for Latent Print Examiners”.¹⁰⁷⁸ Interpol standards published in 2000 and 2004 described procedures and methodologies for European fingerprint examiners.^{1079,1080} While the term “ACE-V” was not specifically used, the documents referred to the stages of fingerprint examination as “Analysis (Information Gathering)”, “Comparison”, “Evaluation (Decision Making)”, and “Verification”. In 2010, SWGFAST updated the methodology standard to be much more detailed, including guidelines for decision making.¹⁰⁸¹

At the 91st Annual Education Conference in Boston, Massachusetts in 2006, another Standardization II Committee was appointed to determine if the 1973 Position Statement on Minimum Information, to the effect of an identification of latent prints, remained valid in the light of

¹⁰⁷⁵ Champod C and Evett IW “A Probabilistic Approach to Fingerprint Evidence” 2001 *J Forensic Ident* 51(2):101-122.

¹⁰⁷⁶ Crispino F “Comments on JFI 51(3)” 2001 *J Forensic Ident* 51(5):449-456.

¹⁰⁷⁷ McKasson SI “Think Therefore I Probably Am” 2001 *J Forensic Ident* 51(3):217-221.

¹⁰⁷⁸ Scientific Working Group on Friction Ridge Analysis Study and Technology (SWGFAST) “Friction Ridge Examination Methodology for Latent Print Examiners (2002). <http://www.swgfast.org/Documents.html> (Date of use: 6 December 2018).

¹⁰⁷⁹ Interpol. Interpol European Expert Group on Fingerprint Identification - IEEGFI *Interpol Reykjavik 17-19 May 2000*.

¹⁰⁸⁰ Interpol. Interpol European Expert Group on Fingerprint Identification II - IEEGFI II *Interpol Lyon 2004*.

¹⁰⁸¹ Scientific Working Group on Friction Ridge Analysis Study and Technology (SWGFAST) “Standards for Examining Friction Ridge Impressions and Resulting Conclusions” ver 1.2 (2011b), <http://www.swgfast.org/Documents.html> (Date of use: 6 December 2018).

research conducted since 1973.¹⁰⁸² In 2007, the newly elected president of IAI, Kenneth Martin, increased the committee size to incorporate members from various scientific, statistical, and legal backgrounds. He wanted to ensure that all stakeholder perspectives were addressed and the results would be truly representative of the relative scientific community. They were tasked with three issues, namely to:

- Determine if, after review of the 1973 Position Statement and the research conducted since that time, the IAI should maintain the position that no valid (scientific) basis exists for requiring a pre-determined minimum number of friction ridge characteristics be present in two impressions to establish an identification, and
- Determine the recommended change and the basis for that conclusion, if the Standardization II Committee concludes that the position of the IAI should change. If no change is warranted, to indicate what would the basis be for maintaining the 1973 position, and
- Determine, upon conclusion of the Committee's review of past and present data, any recommendations regarding research which would further the science.

The committee chairman developed the following list of questions to be researched and answered:

- What recognised research exists regarding the individuality of friction ridge skin detail in, and what existing research can or should be used to support a position statement on this issue?
- What recognised research exists regarding the expression of probability as a means of assigning value to the quantity of Level I and Level II friction ridge characteristics available for use in the analysis, comparison and evaluation process?
- What recognised research exists regarding the weight of specific types of Level I and Level II friction ridge detail which might affect their value in the examination process?
- What are the existing practices regarding friction ridge area individualisations? This question deals specifically with what, if any, formal and published requirements exist in

¹⁰⁸² Polski *IAI Standardization* 2011 [12].

various countries. If a country does not have a numeric standard, e.g. 14, then what is the number? If a country uses a holistic approach, how is the process defined?

- Regarding standards for identification of fingerprints, what recognised work or studies have been published? This could include the efforts of the 1970 IAI Standardisation Committee and any technical and scientific working group established since that time. Finally, to determine, if possible, the extent of research conducted in support of any published position statements, and
- What published standards for conclusions exist within other forensic disciplines?

The committee met various times over the next two years and presented their status report to the IAI Board of Directors in August 2009. The committee made certain recommendations, which were accepted and adopted as resolution 2009-18. The following changes need to be noted:

- A significant volume of research has been published since the adoption of the 1973 Resolution which states, “[...] that no valid basis exists at this time for requiring that a predetermined minimum number of friction ridge characteristics must be present in two impressions in order to establish positive identification. The foregoing reference to friction ridge characteristics applies equally to fingerprints, palm prints, toe prints and sole prints of the human body.” (the “1973 Resolution”)
- This research has been conducted primarily in the medical, anthropological and biological scientific communities.
- The results of this research consistently and overwhelmingly have supported the positions of biological uniqueness (specificity) and persistence, as they pertain to friction ridge skin.
- This extensive research however, has not provided a definitive answer to the question of “*sufficiency*”, that is to say, “*How much friction ridge detail information or area is needed to establish, within a reasonable degree of scientific certainty, donor attribution of a partial friction ridge impression?*” Therefore, the practicing friction ridge examiner, trained to competency, is required to base their opinion not only on the friction ridge detail information under examination, but also upon their individual education, training and experience.
- The IAI recognises that it is impossible to prove that no two individuals possess the same friction ridge arrangement in sequence.

- The IAI recognises that it is an important function of the friction ridge examiner trained to competency to provide the courts, and other agents of the criminal justice system, with an opinion as to the source of a friction ridge impression. Based on the training, experience, and knowledge of the friction ridge examiner, an opinion of source attribution may be provided when such an opinion can be derived, given the quantity, quality, and specificity of the friction ridge detail.
- The IAI also recognises that there is more than one commonly used method for determining sufficiency of friction ridge detail information in sequence in order to arrive at a conclusion. The IAI supports additional research in this vitally important area, including the application of probability modeling which may be used to supplement current practices.

Due in part to the aforementioned statements recognised by the IAI, it is the position of the International Association for Identification that the basic premise upon which the 1973 IAI Resolution was based, was still fundamentally valid. Continued research since 1973 has still not resulted in a definitive answer to the question of “*How much is enough to individualize?*”¹⁰⁸³

In the same timeline, SWGFAST’s policy was published, and all guidelines and standards were open for comment from the community prior to being accepted as final documents. By design, this process was meant to ensure that the final work actually represents and satisfies the needs of practitioners as well as the science community and provided a vision that extends beyond that of just the SWGFAST membership.

To ensure continuous development in the field of practice, a special publication committee was appointed in 1986, and led to the establishment of the *Journal of Forensic Identification*, a peer reviewed journal with original technical articles and case reports in 1986. This journal continues to the present.¹⁰⁸⁴

¹⁰⁸³ Polski IAI Standardization 2011 [12].

¹⁰⁸⁴ IAI Journals. http://www.theiai.org/jfi_journals.php (Date of use: 28 December 2018).

During the time of development of new recommending standards, a number of events redirected certain thought processes towards dealing with issues arising from the community (e.g. Daubert hearings, Mayfield case, NAS Report), some of which will be discussed later in this chapter.¹⁰⁸⁵

7.3.3 Standardisation of expert qualification

Standardisation of the scientific method and procedures is one part of the solution, but the second part required standardised training to be a qualifying expert in the field. From court hearings, it was imminent that those who testified on fingerprint evidence over time would be challenged on their knowledge and expertise. The first relevant case in this regard in the United States was the case of the *State v. Jennings* in 1911, where the court held that the expert had to be a competent witness, whose qualifications as an expert are not questioned,¹⁰⁸⁶ which means, the court did examine the expert's knowledge and experience to determine his/her ability to testify. This was followed by numerous cases throughout all the states.¹⁰⁸⁷ There were no hard and fast rules laid down as to when a person familiar with fingerprints becomes an expert, but as time progressed, the judgments that touched on the issue served as a guide for the next trial. In *Leonard v. State* in 1922,¹⁰⁸⁸ five years' actual experience in fingerprint identification work had been held sufficient to qualify as an expert. The focus was more on where and how long a person was working with fingerprint comparison work, than the quality and rigour of the training.¹⁰⁸⁹ Trial courts determined

¹⁰⁸⁵ SWGFAST Documents. <http://clpex.com/swgfast/Documents.html> (Date of use: 26 December 2018).

¹⁰⁸⁶ *People v. Jennings*, 252 Ill. 534, 96 N.E. 1077 (1911).

¹⁰⁸⁷ *State v. Cerciello*, 86 N.J.L. 309, 90 Atl. 1112 (1914); *People v. Roach*, 215 N.Y. 592, 109 N.E. 618 (1915). Also in *Moon v. State*, 22 Ariz. 418, 198 Pac. 288 (1921); *Robertson v. State*, 168 Tex. Crim. 35, 322 S.W.2d 620 (1959). An expert witness is one possessed of scientific knowledge acquired by study or practice, or both, and is ordinarily a person who has experience and knowledge in relation to matters not generally known: *Pierce v. State*, 371 P.2d 924 (Okla. Crim. App., 1961); *State v. Robinson*, 223 La. 595, 66 So. 2d 515 (1953).

¹⁰⁸⁸ *Leonard v. State*, 18 Ala. App. 427, 93 So. 56 (1922). In Texas, an officer who had been in the identification section of the county sheriff's office for two years and had received training and instruction in fingerprinting under an expert in the department was qualified as a fingerprint expert: *Todd v. State*, 342 S.W.2d 575 (Tex. Crim. App. 1961).

¹⁰⁸⁹ *McLain v. State*, 198 Miss. 831, 24 So. 2d 15 (1945). This case involved a superintendent of police who was a graduate of a recognized fingerprint school, had twelve years of practical experience, and was an officer of the International Association for Identification. *State v. Combs*, 200 N.C. 671, 158 S.E. 252 (1931). The witness had completed a course of instruction approved by the superintendent of the fingerprint department of the United States Army and Navy requiring two years of study. *State v. Viola*, 148 Ohio 712, 82 N.E.2d 306 (1947). The witness was an agent of the bureau, and declared the Federal Bureau of Investigation to be the recognized world authority on fingerprints.

expertise based on the witness's statements while answering qualifying questions. Key components for qualifying as an expert in fingerprint comparison were: formal training in ink print recording and classification; crime scene processing training; and practical experience performing comparisons. No science requirements to understand the physical and chemical properties of the evidence, nor statistical knowledge of probability or likelihoods were necessary to be considered an expert.

In 1977, the IAI established its first Latent Print Certification Board. The board was tasked to establish, implement, and revise standards of qualification for those experts performing analysis in latent fingerprint examinations. They would then certify qualified applicants who complied with the requirements of the program. The standard qualification practice provided guidance to the justice system on what constituted as an expert witness in latent fingerprint examinations. Latent Print Certification Program is a rigorous testing process validating one's expertise in the science of fingerprints.¹⁰⁹⁰ The program is still current and a list of certified experts are displayed on their website.¹⁰⁹¹ Although it is not mandatory, it is concerning to see among those certified, only one person is certified in South Africa, two in the United Kingdom, and two in Australia. For a program that has existed for over three decades, in conjunction with an international organisation for certification, this should be a matter of serious concern in the criminal justice systems and the forensic administration in general. This will be addressed under future developments within fingerprint evidence in this chapter.

7.4 Automation

Besides standardisation, another challenge in the fingerprint community was that of automation. The United States saw a rise in the crime rates during the late 1960s and early 1970s. There was a need for automation in fingerprint searching methods, since latent fingerprints were by far the most frequently retrieved physical evidence recovered from crime scenes. The FBI's Identification Division was established in 1924 with a central repository of criminal identification data for law

¹⁰⁹⁰ IAI History. http://www.theiai.org/iai_history.php (Date of use: 28 December 2018).

¹⁰⁹¹ IAI Documents. https://www.theiai.org/docs/Aug_2019_LP_Name.pdf (Date of use: 19 September 2019).

enforcement agencies. The division started with 810,188 records and by 1960 they had 15 million individuals in the criminal files and 63 million records in the civilian files.¹⁰⁹² The manual searching for prints in the criminal files was not feasible anymore. This was not just a United States problem, but also an international problem. In the early 1960s, the FBI in the United States, the Home Office in the United Kingdom, Paris Police in France, and the Japanese National Police, initiated projects to develop automated fingerprint identification systems. In 1963, Special agent Carl Voelker approached two engineers Raymond Moore and Joe Wegstein from the National Institute of Standards and Technology (NIST) to assist in automating the FBI's fingerprint identification system. After studying the manual process for identification they had three goals: namely to develop scanners that could automatically read and electronically capture the inked or developed fingerprint images; then a method that would accurately and consistently detect and identify minutiae that existed in the captured images, and lastly develop a method that would compare two lists of minutiae descriptors to determine whether they both came from the same finger of the same individual.

By 1976, a new system was implemented and it took the FBI three years to capture the 15 million criminal fingerprint cards electronically.¹⁰⁹³ Although the system still had many flaws, it was not only helpful in automation in searching, but it was a step closer to more objective searching than subjective searching.

In 1969, the French government (Prefecture of Police in Paris) focused on a solution to the latent print problem and not the general identification problem that was the concern in the United States. They incorporated a video camera tube to scan photographic film transparencies of fingerprints.¹⁰⁹⁴ The minutiae matching was based on special purpose, high speed hardware that used an array of logical circuits. Due to the problem of poor fingerprint image quality, a technique was developed in order to acquire a high contrast image that would easily photograph and process

¹⁰⁹² NIJ *Fingerprint Sourcebook* Chapter 6 [4].

¹⁰⁹³ Moore RT "Automatic Fingerprint Identification Systems". In: *Advances in Fingerprint Technology* Lee HC and Gaensslen RE (1st ed Elsevier NY 1991) 163-191.

¹⁰⁹⁴ Thiebault R "Automatic Process for Automated Fingerprint Identification" In: *Proceedings of the International Symposium on Automation of Population Register Systems* (Jerusalem: Publisher not identified 1967) 207–226.

images. Live fingerprint image photography was developed using a principle of “frustrated total internal reflection” (ftir). This technique was not put into large scale until 20 years later when it formed and still forms the cornerstone for modern day live-scan fingerprint scanners. Later in the 1970s, another request by the French ministry to develop an automated fingerprint system gave rise to the well-known Morpho System, developed by the Morphologic Mathematics Laboratory at the Paris School of Mines.

During the same period, the United Kingdom also worked on automated fingerprint identification systems and also focused on latent print work. The work was performed by Ken Millard.^{1095,1096} By 1974, the AFIS readers were able to detect minutiae, record position and orientation, and determine ridge counts for the five nearest neighbors to the right of each minutiae.¹⁰⁹⁷

Back in the United States, the RAND Corporation’s technical report, “The Criminal Investigative Process, Volume III: Observations and Analysis”, appeared in October 1975.¹⁰⁹⁸ In the study Joan Petersilia concluded that:

“No matter how competent the evidence technician is at performing his job, the gathering of physical evidence at a crime scene will be futile unless such evidence can be properly processed and analyzed. Since fingerprints are by far the most frequently retrieved physical evidence, making the system of analyzing such prints effective will contribute the most toward greater success in identifying criminal offenders through the use of physical evidence.”¹⁰⁹⁹

Automated systems were limited to national police agencies and all new government funding was assigned to increase the computerised capacity, as advances were made on new computer

¹⁰⁹⁵ Millard K “An Approach to the Automatic Retrieval of Latent Fingerprints” 1975 In *Proceedings of Carnahan Conference on Electronic Crime Countermeasures* Lexington KY 45–51.

¹⁰⁹⁶ Millard K “Development on Automatic Fingerprint Recognition” 1983 In *Proceedings of the Carnahan Conference on Security Technology* Zurich Switzerland 173–178.

¹⁰⁹⁷ Moore RT “Identification Systems” 1991.

¹⁰⁹⁸ Greenwood PW *et al.* “The Criminal Investigative Process” 1975 (Vols. 1–3) Technical Report R-1777 DOJ Rand Corporation: Santa Monica CA.

¹⁰⁹⁹ Petersilia J “The Collection and Processing of Physical Evidence” 1975 *WN-9062-DOJ Rand Corporation: Santa Monica CA.*

hardware technology.¹¹⁰⁰ Rockwell developed the Printrak system for smaller databases and started to market it at annual conferences. San Jose, California, was the first to implement the beta-site system, which was followed by dozens of other units. San Francisco's mayor insisted on evaluating more systems to benchmark tests and opened a bid for a fingerprint system. The three companies who bid were Printrak (USA vendor), NEC (Japanese vendor), and Logica (European vendor). After a thorough evaluation, NEC was awarded the contract in 1983, due to its organisational design. The San Francisco conviction rate in AFIS-generated burglary crime cases was three times higher than in burglary cases without this type of evidence after application of the system.¹¹⁰¹ The data supported the need for automation on a national and international level.

With these statistics published, governments quickly provided funding for similar evaluations and installations worldwide and by 1999, the International Association for Identification's (IAI's) AFIS Directory of Users identified 500 AFIS sites worldwide.¹¹⁰² Cities, counties, and states installed different systems from four major vendors (Printrak, NEC, Morpho and Cogent), based on their respective needs. They soon realised that these systems were incompatible in data transfer, even between jurisdictions, and an evolution of electronic transmission standards was needed to improve the problem for ten-print searches.

One solution to the problem was the establishment of the Integrated Automated Fingerprint Identification System, known as IAFIS, the world's largest collection (64 million individuals) of criminal history information, on its implementation on July 28, 1999. Since the inception of the IAFIS system at the FBI's Criminal Justice Information Services (CJIS) Division, new technology capabilities were added, legislative directives were embraced, and performance and accuracy of information services were improved. There were also standard requirements established for submission of ten-print and latent prints for searches on the ink-and-paper era. This was not just confined to the United States, but also internationally. As the technology grew, so did the demand for faster turnaround times for identifications. Paper submissions turned to electronic submissions,

¹¹⁰⁰ Wayman J *Biometric Systems* (Springer: New York 2004).

¹¹⁰¹ Bruton T "Annual Report of the Crime Scene Investigations Unit" 1989 *San Francisco Police Department: San Francisco CA*.

¹¹⁰² International Association for Identification "AFIS Directory of Users" IAI: Mendota Heights MN 1999.

and the status of fingerprint searches could be done within hours to remote sites. New standards were approved in November 1993, with the formal title “Data Format for the Interchange of Fingerprint Information”.¹¹⁰³ These new standard requirements allowed for quick exchange of data between agencies on a national and international level. The evolution of the AFIS into a highly efficient and effective tool, capable of scrutinising vast databases and providing potential fingerprint matches in a matter of minutes, is the product of intensive research and development stretching back over five decades. By 1999, 500 AFIS systems were deployed internationally and according to a study conducted by Markets and Markets¹¹⁰⁴ in 2017, the automated fingerprint identification system market size will reach \$8.49 billion by 2020 with Gemalto Cogent, Idemia (formally Morpho), and NEC as the major role players.

With the increase of the international population and capturing more fingerprints on databases, Cherry and Imwinkelried¹¹⁰⁵ proposed a return to the use of the Henry system by looking at neighboring fingers for identification.

¹¹⁰³ American National Standards for Information Systems “Data Format for the Interchange of Fingerprint Information” ANSI/NIST-CSL 1-1993 National Institute of Standards and Technology U.S. Government Printing Office: Washington DC 1993.

¹¹⁰⁴ “Automated Fingerprint Identification System Market worth 8.49 Billion USD by 2020” 2016-02-02 *Markets and Markets*. <https://www.marketsandmarkets.com/PressReleases/automated-fingerprint-identification-system.asp> (Date of use: 31 December 2018).

¹¹⁰⁵ Cherry M and Imwinkelried E “How We Can Improve the Reliability of Fingerprint Identification” 2007 *The Print* vol 23:4-7.

Publications on AFIS (matching,¹¹⁰⁶ indexing and filtering on databases,¹¹⁰⁷ interaction between humans and automated systems,¹¹⁰⁸ and image compression¹¹⁰⁹) saw the light, and continued to show that automatic fingerprint algorithms are not as accurate as trained forensic expert comparisons. The automated systems struggle with many noise sources in fingerprint images and would assign wrong minutiae points to images. Developers of these algorithmic systems looked at false positive and non-match errors made by the systems to gain a better understanding on the limitations of the algorithms. NIST performs periodic tests on fingerprint algorithms from various vendors to ensure their accuracy.¹¹¹⁰ They discovered, for example, that there was a tradeoff between false positive and non-match errors, as when the one is lowered, the other increased and therefore making it difficult on the choice of algorithm to be used.

The Member States of the European Union (and Schengen Associated Countries) implemented the new Schengen Information System II (SISII) in 2018. The SISII AFIS allows all Member States

¹¹⁰⁶ Jain AK *et al.* "On Matching Latent Fingerprints" 2008 in *IEEE Conference on Computer Vision and Pattern Recognition Anchorage AK* 1212-1219.

¹¹⁰⁷ Feng JJ and Jain AK "Filtering Large Fingerprint Database for Latent Matching" 2008 in *19th International Conference on Pattern Recognition (ICPR 2008), Tampa, FL*, 2796-2799. Also, Liang XF *et al.* "A Robust Fingerprint Indexing Scheme Using Minutia Neighborhood Structure and Low-Order Delaunay Triangles" 2007 in *IEEE Transactions on Information Forensics and Security* 2:721-733. Also, Gyaourova A and Ross A "A Novel Coding Scheme for Indexing Fingerprint Patterns" 2008 in *Joint International Workshop on Structural Syntactic and Statistical Pattern Recognition Orlando FL* 755-764.

¹¹⁰⁸ Dror IE and Mnookin JL "The Use of Technology in Human Expert Domains: Challenges and Risks Arising from the Use of Automated Fingerprint Identification Systems in Forensic Science" 2010 *Law Probab Risk* 9:47-67. Also, Davis CJ and Hufnagel EM "Through the Eyes of Experts: A Socio- Cognitive Perspective on the Automation of Fingerprint Work" 2007 *Mis. Quarterly* 31:681-703. Also, Wertheim KE "Human Factors in Large-Scale Biometric Systems: A Study of the Human Factors Related to Errors in Semi-Automatic Fingerprint Biometrics" 2010 *Systems J IEEE* 4:138-146.

¹¹⁰⁹ Allinson NM *et al.* "Robust Wireless Transmission of Compressed Latent Fingerprint Images" 2007 *IEEE Transactions on Information Forensics and Security* 2:331-340. Also, Babb B and Moore F "The Best Fingerprint Compression Standard Yet" 2007 in *IEEE International Conference on Systems Man and Cybernetics Montreal Canada* 3834-3839. Also, Babb B *et al.* "Evolved Transforms Beat the FBI Wavelet for Improved Fingerprint Compression and Reconstruction" 2007 in *6th WSEAS International Conference on Telecommunications and Informatics/ 6th WSEAS International Conference on Signal Processing Dallas TX* 179-184.

¹¹¹⁰ National Institute of Standards and Technology (NIST) "Scientists Automate Key Step in Forensic Fingerprint Analysis: New algorithm may make the process more reliable and efficient" August 14, 2017. <https://www.nist.gov/news-events/news/2017/08/scientists-automate-key-step-forensic-fingerprint-analysis> (Date of use: 20 September 2019).

to leverage on a centralised policing-orientated database, strengthening the fight against crime within Europe.

As more and more prints are taken up on the automated systems, organisations will continue to increase algorithmic enhancements on accuracy and speed for searches against crime scene samples.

7.5 First instances where the law challenged the scientific method

7.5.1 Early fingerprint evidence challenges on trial

The scientific method on fingerprint evidence was developed over more than a century and as was the case with every development in the forensic disciplines, new challenges emerged. Most challenges came from courts which challenged the science on issues of validity and reliability. In this section, the discussion will turn to the first trials and challenges forensic experts faced in various jurisdictions across the globe. The use of fingerprint evidence was not restricted to one country alone, but gained recognition as a scientifically valid and reliable method for identification and individualisation internationally.

The first trial in England that relied on fingerprint evidence involved Detective Sergeant Charles Stockley Collins of Scotland Yard, in 1902. On June 27th, some billiard balls were stolen from a house in Denmark Hill, South London. Collins, who was an expert in the developing science of fingerprint identification, discovered a clear left thumbprint on a recently painted windowsill. He photographed the print before taking it back to laboratory where they searched through known criminals' prints until a similar print was found. The crime scene print was a match to the left thumbprint of 41-year-old Harry Jackson. Although he was not in possession of the billiard balls when the police searched his house, they found other stolen goods from reported burglaries. During the trial, Collins testified to an individualisation made in the burglary case. The 1902 trial and subsequent conviction of 7 years' imprisonment marked the beginning of fingerprint evidence in the courts of England.¹¹¹¹ Although the method of development was not discussed, it followed the

¹¹¹¹ Lambourne *The Fingerprint Story* 1984) [67-68]. Also, Old Police Cells Museums in UK <http://www.oldpolicecellsmuseum.org.uk/content/learning/educational-programmes-and-tours/first-convictions-uk-based-fingerprint-evidence> (Date of use: 12 February 2018).

scientific principles of pattern evidence discovery, development, imaging, comparison and interpretation.

Later the same year in October, Alphonse Bertillon, a French police officer and biometrics researcher, who applied the anthropological technique of anthropometry to law enforcement, investigated the murder of Joseph Reibel. Bloody prints were discovered on a broken glass piece from a cabinet. It was photographed and preserved for identification. After comparing the prints to the victim and matches found, Bertillon began a search of his anthropometric cards, to which by that late date, he had added fingerprint impressions as a routine matter in addition to his measurements. Bertillon found a file card which contained fingerprint impressions that showed areas that matched the prints taken from the broken glass. In his report he described the isolation of three points of resemblance in the thumb print, four in the index and middle finger, and six in the ring finger. It was enough evidence for the court to convict Henri Leon Scheffer.¹¹¹² As a result of the case, Bertillon was given credit for solving the first murder in Europe with the use of only fingerprint evidence. It was also the first case where the combination of adjacent prints in the blood with low minutiae counts was enough to convince the court of its uniqueness.

In 1905, Inspector Charles S. Collins testified again to the individualisation of a suspect's fingerprint on a cash box in the murder of Thomas Farrow and his wife. The two suspects, Alfred and Albert Stratton, left unique prints on the cash box in such a way that Collins could easily explain to the jury the classification of fingerprints and how to effect an individualisation. He demonstrated the characteristics he had marked on a chart as matching Alfred Stratton's right thumb. Collins claimed that in all his years of experience, he had never found two prints to have more than three characteristics in common. In this case, there were 11 characteristics in common.¹¹¹³ When asked the question by the court how many characteristics would warrant a conclusion, he replied that four characteristics would be enough. He based his theory on his years of experience doing comparisons that two people had similar characteristics up to three minutiae points, but he never

¹¹¹² Kingston CR and Kirk PL "Historical development and evaluation of the twelve-point rule in fingerprint identification" 1965 *Int Criminal Police Rev* 20 (186):62-69.

¹¹¹³ National Institute of Justice "Fingerprint sourcebook" Chapter 1, 2009. See <https://www.ncjrs.gov/pdffiles1/nij/225320.pdf> (Date of use: 12 February 2018).

saw four point minutiae similarities. Supplementing eyewitness statements, the individualisation of Alfred Stratton's right thumb impression was the strongest piece of evidence in the case. Both brothers were found guilty of the murders and sentenced to death on May 23rd, 1905.¹¹¹⁴ It is known as the first murder trial in England in which fingerprints were used as evidence. It was also the first known case where a numerical number was given on what constitutes as enough points of similarity for a match.

Also in 1905, in the case of *Emperor v. Abdul Hamid*, a court in India held that:

“No expert was required to testify to the individualization of prints, and an appellate court. They believed that participants in the court could just as easily make a comparison as anyone else and that an expert was not necessary”.¹¹¹⁵

Other courts would later disagree with the position that no expertise was required to individualise fingerprints.¹¹¹⁶ The Court of Criminal appeal in Great Britain refused to interfere with the lower court's decision on the admissibility of fingerprint evidence, and held that standard authorities on scientific subjects discussed the use of fingerprints as a system of identification, and concluded that experienced experts had shown it to be reliable.¹¹¹⁷ The court accepted fingerprint evidence as scientific and reliable.

The first prosecution in New Zealand based on fingerprints alone was recorded at the Supreme Court in Wellington during May 1905. The Chief Justice Sir Robert Stout presided over a jury that convicted John Clancy of housebreaking and theft based on evidence that the impression of his right ring finger corresponded to the impression of that finger registered by the Auckland authorities.

¹¹¹⁴ Cole SA *Suspect Identities* 2001.

¹¹¹⁵ Cole SA *Suspect Identities* 2001.

¹¹¹⁶ *Castleton's Case*, 3 *Crim. App.* 74 (1909); Upon the appeal of *Castleton's Case* the defendant contended that even though the finger-print found on a candle at the scene of the crime (burglary) might have been his, that evidence alone was not sufficient to establish his guilt. But the court said: “The suggestion has been made that these finger-prints have been put there by someone else, but that suggestion was disposed of by the jury, who decided upon the evidence before them. Our attention has been drawn to the photographs and the impression of the finger-prints. Looking at the middle finger particularly, as well as to the index finger of the right hand, we agree with the evidence of the expert at the trial.”

¹¹¹⁷ *Michigan Law Rev* (March 1912) 10:5:396-401.

This judgment is the first conviction on record in New Zealand based on the evidence of a single fingerprint without any supporting evidence.

In the United States, the first conviction on fingerprint evidence was obtained in 1906 in New York as a result of the collaborative effort between the Bertillon Bureau of the Police Department and the Convict Supervision Office, New Scotland Yard.¹¹¹⁸ A notorious criminal had robbed the wife of a prominent novelist in London of £800, before making his escape to New York, and was captured after committing a robbery in one of the large hotels in that city. The Bertillon Bureau of the Police Department took a print of one of his thumbs, which was mailed without any particulars to the Convict Supervision Office, New Scotland Yard, London, where he was identified. He was convicted and sentenced to seven years in prison.

On September 19th, 1910, Clarence Hiller woke up at 2 a.m. to the screams of his wife and daughter at their home in Chicago. After fighting off the intruder down the stairs, Clarence was shot three times and left for dead at the front door. Thomas Jennings was stopped a half a mile away wearing a torn and bloodied coat and in a possession of a pistol. The key evidence was the latent print left behind on a freshly painted railing as the intruder hoisted himself through a window of the premises. Murder suspect Thomas Jennings was convicted in the same year after testimony by four experts who individualised Jennings' fingerprints from the porch railing at the crime scene. All four witnesses testified that the fingerprints on the railing were made by Jennings. Other evidence also incriminated the defendant, such as Jennings's proximity to the murder scene 13 minutes after the murder, while carrying a recently fired pistol containing cartridges similar to ones found at the murder scene. The defence appealed the case, claiming the fingerprint evidence was improperly admitted and that it was not necessary to use a fingerprint examiner as an expert witness. The defence team solicited prints from the public in an effort to find a similar print to that of the recovered print from the railing in an effort to disprove individuality and that prints can repeat itself through different sources. Defence attorney, W. G Anderson, even challenged the examiners to lift a print from a piece of paper he touched, but his attempt backfired as they were able to identify

¹¹¹⁸ Laufer, *History of the Finger-Print System* 631-652, Ann. Rep. Smithson. Inst. (1962). The author states: On May 2, 1906, the Evening Post of New York announced in an article titled, "Police Lesson from India" the first successful application in this country of the thumb-print test.

him as the source of the print. This made a distinct impression on the jury and they voted unanimously to convict Jennings. After the conviction, Jennings' lawyers mounted a challenge to the notion that such a newfangled technique should not have been submitted to trial. On December 21st, 1911, the Supreme Court upheld the conviction and affirmed the sentence of Jennings. The court cited several prior cases from Britain and published studies on the subject in support of the credibility of fingerprint individuality. Chief Justice Carter of the Illinois appellate court, in confirming the conviction, stated as follows:

"We are disposed to hold from the evidence of the four witnesses who testified and from the writings we have referred to on this subject, that there is a scientific basis for the system of finger-print identification and that the courts are justified in admitting this class of evidence; that this method of identification is in such general and common use that the courts cannot refuse to take judicial cognizance of it. From the evidence in this record we are disposed to hold that the classification of finger-print impressions and their method of identification is a science requiring study. While some of the reasons which guide an expert to his conclusions are such as may be weighed by any intelligent person with good eyesight from such exhibits as we have here in the record, after being pointed out to him by one versed in the study of fingerprints, the evidence in question does not come within the common experience of all men of common education in the ordinary walks of life, and therefore the court and jury were properly aided by witnesses of peculiar and special experience on this subject."¹¹¹⁹

The ruling also stated that:

"Expert testimony is admissible when the subject matter of the inquiry is of such a character that only persons of skill and experience are capable of forming a correct judgment as to any facts connected therewith."

For the purpose of the law, the inclusion of this statement was crucial at the time, as it allowed room for human judgment and interpretation during analysis and throughout the court process when friction ridge evidence was presented to the jury. Two fundamental questions were claimed to be answered during the trial in the admissibility of the evidence, namely those relating to the

¹¹¹⁹ *People v. Jennings* 1911 [9–10]. Also United States Department of Justice, Fingerprints, (Washington, D.C.: United States Government Printing Office, 1934) [22]. [Referring to *People v. Jennings*, 252 Ill., 534; and 96 Northeastern Reporter, 1077.]

soundness of the technique, and secondly to the accurateness of the interpretation of the evidence.

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After being upheld on appeal, *People v. Jennings* became a landmark judgment, because it was the first American appellate case regarding the admissibility of fingerprint expert testimony. The appeal court concluded that fingerprint identification is a science and that expert testimony was appropriate to aid members of the court in understanding fingerprint evidence.

In 1911, in *People v. Crispi*,¹¹²¹ Lieutenant Joseph Faurot, a New York Police Department fingerprint expert, presented testimony in a burglary case. He individualised defendant Charles Crispi's fingerprint on a pane of glass removed from a door at the crime scene point of entry. In a courtroom demonstration, Faurot involved all 12 jurors by taking their prints and requested that in his absence, one juror had to leave one print on a drinking glass. He later returned and pointed out the juror who left the print. He then handed each juror a set of charts involving the case and showed marked characteristics in common between the known print of Crispi and the unknown print left on the scene. It enabled them to follow the comparison method between the prints. The demonstrations were so impressive that the defendant changed his plea to guilty.¹¹²²

Edward Parker was tried at the Court of General Sessions at Melbourne, Australia,¹¹²³ on a charge of breaking into a shop and stealing contents from a safe during a weekend in February, 1912. A latent print on a bottle in the store revealed the left middle finger of Parker as the source. It was the only evidence against Parker. Enlarged photographs of both the latent fingerprint from the bottle and known prints taken from the accused were detailed by the detective in charge of the fingerprint branch of the Criminal Investigation Department. Nine points of similarity in the arrangement of the ridges on both prints were given. In addition to the natural contour of Parker's left middle finger, there were two scars nearly at right angles to one another, and the print taken from the bottle presented the same marks. The Chairman of General Sessions stated a case for the determination

¹¹²⁰ Cole SA *Suspect Identities* 2001.

¹¹²¹ *People v. Crispi*, 106 App. Div. 176, 94 NYS 372, 94 NY 372 – 1911.

¹¹²² Cole SA *Suspect Identities* 2001 [181–185]; Wilder and Wentworth *Methods for identification* 1918, [283–284].

¹¹²³ *Parker v. The King*, 14 C. L. R. 681 (1912), 3 Br. Rul. Cas. 68 (1914).

by the Supreme Court of the question whether, when the only evidence of identity against an accused person depends upon the resemblance between finger prints, such evidence is sufficient to support a conviction.

In the 1915 case, of *People v. Roach*,¹¹²⁴ the matter of fingerprint evidence arose before the New York Court of Appeals. The defence insisted that the admission in evidence of the testimony of an alleged expert as to fingerprint impressions was a prejudicial error necessitating a reversal of the conviction. The court ruled that the defence had ample occasion to cross-examine the expert at length as to every detail of his testimony, and that an ample basis was thus afforded for the jury to come to an intelligent conclusion as to the correctness of the opinion he expressed. The court pointed out that it could not rule, as a matter of law, whether fingerprint evidence was incompetent in view of the fact that those charged with the detection of crime in police departments of the larger cities of the world will use it as a means of identification. Thereafter it was generally held in many states that fingerprint evidence, when competent, relevant, and material, is admissible to prove the identity of the accused.¹¹²⁵

¹¹²⁴ *People v. Roach* (1915).

¹¹²⁵ Moenssens AA "Admissibility of Fingerprint Evidence and Constitutional Objections to Fingerprinting Raised in Criminal and Civil Cases" 1963 *Chicago-Kent Law Rev* 40(2):85-124.

Duree v. United States, 297 Fed. 70 (8th Cir. 1924).

ALA: *Sims v. State*, 253 Ala. 666, 46 So. 2d 564 (1950).

ARIZ: *Moon v. State*, 22 Ariz. 418, 198 Pac. 288 (1921).

ARK: *Hopkins v. State*, 174 Ark. 391, 295 S.W. 361 (1927).

CALIF: *People v. Van Cleave*, 208 Cal. 295, 280 Pac. 983 (1929).

CONN: *State v. Chin Lung*, 106 Conn. 701, 139 At. 91 (1927).

FLA: *Martin v. State*, 100 Fla. 16, 129 So. 112 (1930) (admissible if it does not result in a miscarriage of justice or violate fundamental rules of evidence); *Coco v. State*, 80 So. 2d 346 (Fla. 1955), cert. denied, 349 U.S. 931, 75 Sup. Ct. 774, 99 L. Ed. 1261.

GA.: *Lewis v. State*, 196 Ga. 755, 27 S.E.2d 659 (1943).

IDAHO: *State v. Martinez*, 43 Idaho 180, 250 Pac. 239 (1926).

IOWA: *State v. Williams*, 197 Iowa 813, 197 N.W. 991 (1924).

KANSAS: *State v. Martin*, 175 Kan. 373, 265 P.2d 297 (1953).

KY.: *Hornsby v. Commonwealth*, 263 Ky. 613, 92 S.W.2d 773 (1936).

LA.: *State v. Edwards*, 232 La. 577, 94 So. 2d 674 (1957).

MD.: *Debinski v. State*, 194 Md. 355, 71 A.2d 460 (1950).

MASS.: *Commonwealth v. Bartolini*, 299 Mass. 503, 13 N.E.2d 382; cert. denied, 304 U.S. 562, 58 Sup. Ct. 950, 82 L. Ed. 1531 (1939).

MICH.: *People v. Chimovitz*, 237 Mich. 247, 211 N.W. 650 (1927); *People v. Les*, 267 Mich. 648, 255 N.W. 407 (1934).

MISS.: *Willoughby v. State*, 154 Miss. 653, 122 So. 757, (1929); *McLain v. State*, 198 Miss. 831, 24 So. 2d 15 (1945).

In 1918, in Nevada in the United States, the focus of an appeal in the case of the *State v. Kuhl*,¹¹²⁶ was the admissibility of a bloody impression made by the palm of the suspect's hand, taken from an envelope found at a murder scene. The appellate court prefaced its opinion with the remark that although there was no doubt as to the admissibility of fingerprint evidence, due consideration had to be given to the defendant's contention that the science of palm-prints had not developed sufficiently to bear out the conclusion of an expert on the subject. A thoroughly researched opinion by the expert, in which a convincing case was made of the literature relating to finger-prints and palm-prints, led to the court's decision that the circumstantial evidence derived from both prints was equally reliable and therefore in this case expert testimony was properly admitted for the purpose of establishing the guilt of an accused individual having identical palm-prints. For the first time in court, the use of friction ridge skin comparison was not limited to fingerprints alone, but extended to palm friction skin.

The Bureau of Naval Personnel of the United States published a book, "Finger-print Evidence"¹¹²⁷ in 1920. The book contained 25 cases related to fingerprint evidence in criminal trials in India and

MO.: *State v. Richetti*, 343 Mo. 1015, 119 S.W.2d 330 (1938) (admissible where expert testifies prints are legible and are identical with those of accused).

NEV.: *State v. Kuhl*, 42 Nev. 185, 175 Pac. 190 (1918).

N.J.: *State v. Cerciello*, 86 N.J.L. 309, 90 Atl. 1112 (1914); *State v. Connors*, 87 N.J.L. 419, 94 At. 812 (1915); *Lamble v. State*, 96 N.J.L. 231, 114 At. 346 (1921).

N. MEX.: *State v. Johnson*, 37 N.M. 280, 21 P.2d 813 (1933).

N.Y.: *People v. Roach*, 215 N.Y. 592, 109 N.E. 618 (1915).

NO. CAR.: *State v. Combs*, 200 N.C. 671, 158 S.E. 252 (1931); *State v. Helms*, 218 N.C. 592, 12 S.E.2d 243 (1940).

OHIO: *State v. Viola*, 148 Ohio 712, 82 N.E.2d 306 (1947).

OKLA.: *Stacy v. State*, 49 Okla. Crim. 154, 292 Pac. 885 (1930).

PA.: *Commonwealth v. Loomis*, 270 Pa. 254, 113 At. 428 (1921); *Commonwealth v. Albright*, 101 Pa. Super. 317, 321 (1931) ("Its [fingerprint evidence's] accuracy and reliability are too well established to require elaborate confirmation. . .").

TEXAS: *McGarry v. State*, 82 Tex. Crim. 597, 200 S.W. 527 (1918). *Grice v. State*, 142 Tex. Crim. 4, 151 S.W.2d 211 (1941).

VT.: *State v. Lapan*, 101 Vt. 124, 141 At. 686 (1928); *State v. Watson*, 114 Vt. 543, 49 A.2d 174 (1946).

WASH.: *State v. Witzell*, 175 Wash. 146, 26 P.2d 1049 (1933); *State v. Johnson*, 194 Wash. 438, 78 P.2d 561 (1938).

W. VA.: *State v. Johnson*, 111 W. Va. 653, 164 S.E. 31 (1932); *State v. Lawson*, 125 W. Va. 1, 22 S.E.2d 642 (1942).

WYOM: *Waxler v. State*, 67 Wyo. 396, 224 P.2d 514 (1950).

¹¹²⁶ Nev. 185, 175 Pac. 190, 3 A. L. R. 1694 (1918). The use of a projectoscope was approved in this case.

¹¹²⁷ Finger-print Evidence, United States. Bureau of Naval Personnel, 1920.

<https://books.google.com/books?id=3fzlAAAAMAAJ&pg=PA25&lpg=PA25&dq=3+Nagpur,+L.+Re>

the United States. In some of the cases, demonstrations by the prosecution were allowed to show the accuracy of the discipline.¹¹²⁸ Over time, these demonstrations disappeared from the trial courts proceedings, as the fingerprint comparison method became judicially recognised in most jurisdictions.

In 1938, the Supreme Court of Washington State upheld the decision of the Superior Court of King County in the conviction of Harry Johnson as a repeat offender. In the case, a fingerprint expert was called to testify in the capacity of the person who took the fingerprints of Johnson in the King county jail in 1936. The expert witness was then asked to compare those original fingerprint records of Johnson with certified copies of records from California and Oregon on previous convictions of Johnson. He testified that all fingerprint records were made by the “same man”.¹¹²⁹

Judge Simpson upheld the decision based on two challenged points, namely (1) whether the certified copies can be accepted when convicting habitual offenders, (2) whether the identification of individuals may be accepted by means of a comparison of fingerprints in the State of Washington. He referenced the following in his statement:

“The introduction of the certified copies of judgments of convictions in the courts of California and Oregon was proper and in accordance with the provisions of Rem. Rev. Stat., SS 1254 [P. C. SS 7773]. *State v. Rowan*, 84 Wash. 158, 146 Pac. 374; *Allard v. La Plain*, 147 Wash. 497, 266 Pac. 688.” and;
“Identification of individuals by means of comparison of fingerprints is generally accepted in this and other states. *State v. Bolen*, ...; *State v. Witzell*, ...; *People v. Sallow*, ...; *Stacy v. State*, ...; *People v. Les*, ...; *Piquett v. United States* [...]”¹¹³⁰

[p.+1+\(India+1904\).&source=bl&ots=AdVRWJPggC&sig=3kd1qtRPVyk2V4_WJ_Uqx8zCfFk&hl=en&sa=X&ved=2ahUKewjUINzJv53fAhVQ2FkKHZiqBACQ6AEwBnoECAGQAQ#v=onepage&q=3%20Nagpur%2C%20L.%20Rep.%201%20\(India%201904\).&f=false](https://www.india.gov/press-releases/india-1904) (Date of use: December 13, 2018).

¹¹²⁸ *Moon v. State*, 22 Ariz. 418, 198 Pac. 288 (1921); *People v. Chimovitz*, 237 Mich. 246, 211 N.W. 650 (1927), and *State v. Dunn*, 161 La. 532, 109 So. 56 (1956).

¹¹²⁹ *State v. Johnson*, 194 Wash. 438, 78 P.2d 561 (1938).
<http://courts.mrsc.org/washreports/194WashReport/194WashReport0438.htm> (Date of use: 13 December, 2018).

¹¹³⁰ *State v. Bolen*, 142 Wash. 653, 254 Pac. 445 (1927). Fingerprint records kept by the War Department of Walter F. Fleming corresponded with a headless body floating in the Columbia river on July 29th, 1925. Fleming was working for Roy Bolen as a farm laborer. Bolen was in financial trouble and increased the insurance on his farm buildings. Fleming disappeared the same day that all buildings were destroyed by fire and Bolen wanted to blame the fires on Fleming.

In 1940, a court in Hamilton, Texas, declared the fingerprint method of identification to be valid. Newton Grice was convicted of burglary based on his fingerprint on a pane of glass removed from a door. Grice appealed the conviction on the grounds that the fingerprint evidence was insufficient to prove that he had been at the location and handled the item in question. In 1941, the appellate Judge, Thomas Beauchamp, stated as follows:

“In various branches of Government activities finger prints are taken by the multiplied thousands. They have been assembled, classified, and indexed systematically and if there are two alike in the great number of which there is authentic record and available to litigants and others interested in the subject, that fact could be definitely proven and the claims of experts successfully contradicted. So far as we have been able to tell, no such contention has ever been so rebutted.”¹¹³¹

Judge Beauchamp overlooked the difference between full known ten print records and the number of minutiae found on the partial latent print. He further emphasised that defence attorneys needed to take the time to actually find prints that are in common in two different individuals, rather than simply make the argument that it is possible. Judge Beauchamp upheld the conviction and stated that fingerprints are unique, hence placing the burden of proof on the defence to prove that fingerprints are not unique.¹¹³²

In 1948, in *Parson v. State*,¹¹³³ the court held that the accused was entitled to subpoena every written report and statement of the prosecution’s expert. In *United States v. Rich* in 1922, it was

<http://courts.mrsc.org/washreports/142WashReport/142WashReport0653.htm> (Date of use: 13 December 2018). *State v. Witzell*, 26 P.2d 1049 (Wash. 1933). Judge Mitchell affirmed conviction of Wallace Witzell in committing a crime of larceny on September 8th, 1930. Witzell argued that the photographed latent prints found on a piece of broken door entering the room of the blown-up safe was inadmissible. Judge Mitchell stated that the evidence, though circumstantial, was, in their opinion, abundant and clearly sufficient and proven to be his prints.

<https://www.courtlistener.com/opinion/4217309/state-v-witzell/> (Date of use: 13 December 2018)

¹¹³¹ Cole SA *Identities: A History of Fingerprinting and Criminal Identification* (Cambridge MA: Harvard University Press 2001).

¹¹³² Fingerprint and Identification 1942.

<https://books.google.com/books?id=PXgtAQAAAJ&printsec=frontcover#v=onepage&q&f=false> (Date of use: 20 January 2020).

¹¹³³ *Parson v. State*, 251 Ala. 467, 38 So. 2d 209 (1948). Also *United States v. Rich*, 6 Alaska 670 (1922), where it was held that the defense should have been permitted to have a photograph of fingerprints allegedly made by defendant on a piece of glass, in possession of the prosecution,

acknowledged that the defence should have been permitted to examine the evidence, but in the case of Parson, it was ordered by the court to hand over all discoveries made by the expert.

From the earliest court cases, involving fingerprints, attention had to be given to standardisation, qualification standards for experts, and a statistical foundation for inferences made. The conclusions made from courts were: the acceptance of the term individualisation based on latent prints left behind on crime scenes to a suspect; acceptance of fingerprint comparisons as a sound and valid technique; the opinion of individuality had to come from a person who is skilled and trained in the discipline, after which the fingerprint comparison method became judicially recognised in most jurisdictions.

In his law review in 1963, Andre Moenssens stated that the reliability of fingerprint evidence is a system of identification and that the practice of taking and comparing fingerprints rested on a substantial scientific basis. He added that this scientific practice had been so universally admitted both in the US and internationally, that courts were taking judicial notice of the fact that there are no two sets of fingerprints alike and that fingerprints are a means of identifying individuals.¹¹³⁴

which intended to use it against defendant at trial, for the purpose of allowing defense experts to examine the prints.

¹¹³⁴ Moenssens Admissibility of Fingerprint Evidence 1963.

UNITED STATES: *Piquet v. United States*, 81 F.2d 75, 81 (7th Cir. 1936) ('This court will take judicial knowledge of the well-recognized fact that fingerprint identification is one of the surest methods of identification known, and that it is universally used in the detection of criminals.').

CALIF.: *People v. Adamson*, 27 Cal. 2d 478, 495, 165 P.2d 3 (1946) ('Fingerprints are the strongest evidence of identity of a person. ...').

MD.: *Murphy v. State*, 184 Md. 70, 40 A.2d 239 (1944).

N.J.: *Lamble v. State*, 96 N.J.L. 231, 114 Atl. 346 (1921).

N.M.: *State v. Johnson*, 37 N.M. 280, 21 P.2d 813 (1933).

NO. CAR.: *State v. Rogers*, 233 N.C. 390, 64 S.E.2d 572 (1951).

OKLA.: *Stacy v. State*, 49 Okla. Crim. 154, 292 Pac. 885 (1930).

TEXAS: *Bingle v. State*, 144 Tex. Crim. 180, 161 S.W.2d 76 (1942).

VT.: *State v. Lapan*, 101 Vt. 124, 141 At. 686 (1928) ('The subject is one of the things that does not have to be proved.').

WASH.: *State v. Bolen*, 142 Wash. 653, 254 Pac. 445 (1927) (Records of War Department bearing fingerprints).

WISC: *Bridges v. State*, 247 Wisc. 350, 19 N.W.2d 529 (1945).

7.5.2 *Fingerprint evidence fallibility and recovery in trials*

The previous challenges regarding the validity of the discipline as a science continued in the context of the use of fingerprint evidence in criminal proceedings. Not all cases had success stories for the prosecution, and over time more people became aware of the value and limitations of fingerprints. Defence attorneys took a closer look at fingerprint evidence and started consulting experts outside the field of law enforcement for assistance. It paid off and the once infallible, so-called errorless foundation of fingerprint evidence showed its first cracks in the courtroom.

7.5.2.1 *Shirley McKie*

The first noteworthy case of mistaken identification in fingerprint evidence in the late 1990s was that of detective constable Shirley McKie's, whose latent print was included on a murder scene she claimed not to have entered at all. In January 1997, Margret Campbell Ross was found dead in her house in Kilmarnock, Scotland. McKie was part of the original murder investigation team. The fingerprint bureau of the Scottish Criminal Record Office (SCRO) in Glasgow recovered 428 fingerprints from the scene, one of which was claimed to belong to McKie, lifted from a door frame of the bathroom of the house. Another one of interest was the print of Ross on a tin containing money found in the house of Asbury, who was later convicted in 1997 of the murder. During the trial, claims of planted fingerprints were made by the defence, but McKie testified that she was never went beyond the porch and did not accept the fingerprint as hers.¹¹³⁵

After the murder trial, McKie was prosecuted for the crime of perjury on the basis that she had lied while giving evidence under oath. During her trial in 1999, two American fingerprint experts, Pat Wertheim and David Grieve, testified about a misidentification on the claimed print of McKie, and the jury unanimously found McKie not guilty. The case attracted a lot of media attention and led to various enquiries from experts as far away as Holland, Norway and Denmark. The results raised alarm bells regarding the work of the SCRO. In 2000, Mr. Asbury was released from prison pending the hearing of an appeal against his conviction. Four SCRO experts were suspended and their

¹¹³⁵ The Fingerprint Inquiry Report 2011. Published on behalf of "*The Fingerprint Inquiry by APS Group Scotland*".

previous cases were reviewed again. No errors were found in any of the cases. McKie subsequently filed a civil action against the SCRO and others for malicious prosecution and in 2006 a settlement was reached.

7.5.2.2 *Stephan Cowans*

Another fingerprint misidentification was discovered in 2004 after Stephan Cowans served seven years in jail for a crime he did not commit. On May 30th, 1997, a Boston police officer was shot twice with his own service pistol after a struggle with an unknown assailant in the backyard of a house in Jamaica Plain. The suspect fled the scene leaving behind his baseball cap and entered the house of Bonnie Lacy and her children. He left the firearm, a white t-shirt and a fingerprint on a glass from which he drank water at the scene. The assailant was later identified as Stephan Cowans. The police officer and a neighborhood resident identified Cowans as the shooter. Bonnie Lacy could not identify him as the person in her house. The fingerprint on the glass mug was identified as that of Cowans. No DNA samples were collected at the time, and the jury convicted Cowans based on the certainty of identification by the officer, the neighborhood resident, and the fingerprint. The case was upheld on appeal in 2001 (in the case of *Commonwealth v. Stephan Cowans*).¹¹³⁶ On May 2003, the Suffolk Superior Court issued an order approving a stipulation – entered into between the Innocence Project, Cowans’s counsel, and the Commonwealth – for the release of the glass mug, swabs taken from the mug, a baseball hat, and the white t-shirt for the purposes of DNA testing. The tests revealed conclusive results that Cowans was not the primary source of the DNA. After the DNA result, the fingerprint evidence was re-examined and showed that the print did not match that of Cowans and he was exonerated in January 2004.

7.5.2.3 *Byron Mitchell*

The scales of justice tilted slightly back in favour of fingerprint evidence in 1999. A well-known legal challenge on the admissibility of fingerprints arose in the case of *U.S. v. Mitchell*.¹¹³⁷ On September 12th, 1991, two men with handguns robbed an armoured car employee of approximately \$20,000

¹¹³⁶ *Commonwealth v. Stephan Cowans*, 52 Mass. App. Ct. 811 (2001).

¹¹³⁷ *US v. Byron Mitchell* 365 F. 3d 215, 246, 1999.

in North Philadelphia. The robbers managed to escape in a beige getaway car, driven by a third person, Byron Mitchell. A partial print of Mitchell was found on the gear shift and driver's side door of the beige getaway car, which they abandoned when switching cars. Also left in the car was an anonymous letter by someone who observed the robbers exiting the beige car and getting into a different car. It also provided the identification of the other car (Mitchell's own car). Mitchell was charged with conspiracy to commit, and the commission of a Hobbs Act robbery, 18 U.S.C of 1951, as well as the use of and carrying a firearm during a crime of violence. Although convicted in the first trial in 1998, the case went on appeal, where the note was held to be inadmissible hearsay evidence and not subject to any exception in Federal Rules of Evidence 803.¹¹³⁸ Mitchell's conviction was vacated and a new trial remanded. The second trial saw the first serious Daubert challenge six years after the Daubert hearing, in which Judge Joyner denied the defence's motion *in limine* to bar the prosecution's expert witness from testifying. A 5-day Daubert hearing on the admissibility under Federal Rules of Evidence 702 was held. The prosecution called six experts as well as one rebuttal witness, and the defence four experts. During the Daubert hearing, a special agent of the FBI, Steven Meagher, testified about 1st-, 2nd-, and 3rd -level detail, as well as other aspects of fingerprint identification. He also testified about the ACE-V protocol; that the FBI does not rely on a minimum "points" standard for matching fingerprints (and why not); and about the AFIS computer system (which automates some preliminary aspects of fingerprint matching). Meagher also described a survey¹¹³⁹ (almost an informal black box study) of the state fingerprint

¹¹³⁸ *United States v. Mitchell*, 145 F.3d 572 (3d Cir. 1998).

¹¹³⁹ For purposes of this case, Meagher created a survey packet that was sent out to the principal law enforcement agency of each of the fifty states, plus the District of Columbia, Canada's Royal Canadian Mounted Police, and the United Kingdom's Scotland Yard. The survey contained three parts: Part A involved questions about whether the agency currently accepts fingerprints as a means to individualize (i.e., make an identification), and about whether the agency regards fingerprints as unique and permanent. All fifty-three recipients responded in the affirmative to both queries. Joint Supp.App. [56]. Part C inquired whether the agencies had ever found two individuals to have the same fingerprint; the response was, unanimously, no. Part C also revealed that, in the aggregate, the ten-print records of nearly 70 million individuals-or about 700 million fingerprints-have been examined during the course of the agencies' operations. Part B of the survey was designed as a demonstration of the ACE-V identification protocol, and it used the latent fingerprints at issue in this case. Part B offered each agency photographs of the two latent prints and of Mitchell's ten-print card. Agencies were asked first to attempt to identify the ten-print card using their own computerized fingerprint database. It is common practice (for efficiency's sake) to "filter" the database in making an identification, by considering only the subset of records (by race, sex, date of birth, etc.) that are likely to result in a match. Meagher requested that agencies not filter their database for this test, to ensure that the prints were compared against the

identification agencies that he prepared and circulated for the purpose of demonstrating that the fingerprint match in this case was, by wide consensus, correct.¹¹⁴⁰ He also described an experiment conducted by him and the AFIS contractor, Lockheed Martin, which would search a portion of the AFIS database for identical fingerprints. The two other experts involved in the experiment, Donald Zeisig (Expert at Lockheed Martin) and Bruce Budowle (statistician and population geneticist with the FBI), also testified. The other two experts focused on the biological aspects of fingerprints. Dr. William Babler, of Marquette University, testified on prenatal development of friction ridges and the unique arrangements of friction ridges that develop in the womb within months after conception. He also testified on the medical community's acceptance of the anatomical and cellular bases for the permanence of friction ridge arrangements. Ed German, of the United States Army Criminal Investigation Laboratory, gave evidence on the lack of similarity found between corresponding fingerprints of identical twins, a conclusion established by his own research on identical twins, and confirmed by other studies of identical twins. The last evidence came from David Ashbaugh of the Royal Canadian Mounted Police, who testified broadly about the development, comparison, and identification of friction ridge skin and impressions. The defence's first witness, Marilyn Peterman, an investigator with the Defender Association of Philadelphia, challenged the survey conducted by Meagher, as well as the varying levels of experience and accreditation of the examiners who performed the comparisons for the agencies. The second expert witness, Dr. David Stoney, Director of the McCrone Research Institute in Chicago, stated in his testimony that when a latent fingerprint examiner makes a conclusion about the source of a latent print to an individual, that determination is scientific.

The essence of Dr. Stoney's opinion is summarised in a portion of his testimony as follows:

"The determination that a fingerprint examiner . . . makes when comparing a latent fingerprint with a known fingerprint, specifically the determination that there is sufficient basis for an absolute identification, is not a scientific determination. . . . It is a subjective determination without objective standards to it. Now, by "subjective" I mean that it is one that is dependent on the individual's expertise, training, and the consensus of their agreement of other individuals in the field. By "not scientific" I mean that there is not an

maximum possible number of print records. Of the forty-seven agencies that responded, the only match that was found was in Pennsylvania, where Mitchell's ten-print record was already on file.

¹¹⁴⁰ United States v. Mitchell 1998 [223].

objective standard that has been tested; nor is there a subjective process that has been objectively tested. It is the essential feature of a scientific process that there be something to test, that when that something is tested, the test is capable of showing it to be false.”¹¹⁴¹

He also gave an opinion on the evaluation phase of the ACE-V protocol that requires the examiner to make a binary determination: either two prints match sufficiently to make an absolute identification, or they do not. He also scrutinised the experiment conducted by Meagher. The third expert for the defence was James Starrs, a professor in the Department of Forensic Sciences and the Law School at George Washington University. He provided an opinion as to whether latent fingerprint examination meets the criteria of science and stated that:

“The current practice of fingerprint comparison and analysis is not predicated on a sound and adequate scientific basis for purposes of making an individualization to one person from a fragmentary print to the exclusion of all other persons in the world.”¹¹⁴²

He highlighted five aspects of fingerprint examination that were inconsistent with scientific disciplines, namely:

- Claims to “absolute” certainty;
- the failure to carry out controlled empirical-data-searching experimentation;
- a failure to engage in error-rate analysis;
- the lack of uniformity, objectivity, systematisation, and standards;
- a failure to show a due regard to a vigorous and uncompromising skepticism.

The fourth and final witness was Simon Cole, a post-doctoral fellow at Rutgers University, with expertise in “science and technology” studies with particular expertise regarding the fingerprint profession. He described four explanations for the widespread acceptance of fingerprint identification evidence:

¹¹⁴¹ United States v. Mitchell 1998 [764a].

¹¹⁴² United States v. Mitchell 1998 [227].

- From the earliest days of the discipline, fingerprint examiners have developed an “*occupational norm of unanimity*,” i.e., examiners would not publicly disagree with one another about an identification.
- In terms of the way in which the fingerprint examination community handled the instances of known misidentification, it could be blamed on practitioner incompetence or misconduct.
- A simple lack of judicial scrutiny - a kind of snowball effect of stringing citations to cases and treatises approving fingerprint identification evidence.
- A lack of an organised counter-expert group.

Dr. Cole also pointed out the lack of science in fingerprints related to falsifiability studies within the community and the lack of peer reviewed articles, as well as the omission of not recognising error rates.

To further support his argument, Mitchell also submitted hundreds of pages of documentary exhibits, including journal articles and other experts from the corpus of literature criticising the practice and theory of latent fingerprint identification. He also provided proficiency test results, which suggested that examiners were prone to both false negatives and false positives. The defence also submitted a survey conducted on juror perceptions of the validity of science in fingerprint identification; e.g. that 93 % agreed with the statement, and 85 % agreed with the statement that fingerprints are the most reliable means of identifying a person.¹¹⁴³

After two months, Judge Joyner concluded that fingerprint evidence satisfied all *Daubert* factors and also acknowledged that “human friction ridges are unique and permanent throughout the area of the friction ridge skin, including small friction ridge areas”. He stated that:

“The matter presently pending before the Court is in reference to the defense motion to exclude the government's fingerprint identification evidence, and based on the Daubert hearing and also Kumho, this Court denies the defendant's motion. And pursuant thereto, this court is not going to make a determination as to the particular area of scientific knowledge and technical or specialized knowledge.

¹¹⁴³ United States v. Mitchell 1998 [229].

Further, pursuant to this Court's ruling, this Court finds that the government's fingerprint evidence is highly probative and substantially outweighs any danger of unfair prejudice to defendant.

We find that the government's expert witness-at this juncture it appears it's Duane Johnson [sic Wilbur Johnson?], an FBI latent fingerprint examiner who testified first in the previous trial, and those other latent experts that testified in the Daubert hearing-are capable of testifying in these proceedings, and in that regard, I am not going to limit the defense from calling latent fingerprint experts to testify as to the ability not to identify or make an identification from the fingerprints, and I am also going to allow the defense to call any latent fingerprint expert who indicates that fingerprints are not reliable sources of information.

Only for that limited purpose and I am going to exclude evidence as to whether or not [latent fingerprint identification is] scientific, technical, or whatever. It has no relevance before the jury here. The question is whether or not an identification can be made by examination of fingerprints-latent fingerprints.”¹¹⁴⁴

On February 7th, 2000, after a lengthy trial, the jury returned with a guilty verdict on all accounts and Mitchell was thereafter convicted. This judgment is regarded as a victory for fingerprint evidence and methods applied to form opinions.

Another motion for a new trial was filed on May 15th, 2000, after the discovery of a research proposal solicitation released by the National Institute of Justice, titled, “Forensic Friction Ridge (Fingerprint) Examination Validation Studies”. The solicitation sought proposals for research studies on “validation of the basis for friction ridge individualization and standardization of comparison criteria”. Creation of the solicitation had been underway before Mitchell's trial, but the solicitation was not released until March 2000, after Mitchell's trial had concluded.

7.5.2.4 *Wade Havvard*

In the same period of the appeal of Mitchell, a court applied the *Daubert* standards to a fingerprint case in *U.S. v. Havvard*.¹¹⁴⁵ The court found that “latent print identification had been *tested* for nearly 100 years in adversarial proceedings with the highest possible stakes - liberty and sometimes life.” Some scholars maintain that the “testability” requirement was misinterpreted by

¹¹⁴⁴ *U.S. v. Mitchell* 365 F.3d 215 (3d Cir. 2004), [3].

¹¹⁴⁵ *U.S. v. Havvard*, 260 F.3d 597, 56 Fed. R. Evid. Serv. 900 (7th Cir. 2001).

the court and should require empirical testing.¹¹⁴⁶ In the law review of Giannelli,¹¹⁴⁷ it is argued that the testimony based on scientific knowledge should have better been scrutinised for its scientific validity. Giannelli asserts that in order to qualify as scientific knowledge, experts should derive an inference or assertion by a scientific method, which should be supported by appropriate validation similar to that of DNA testing.¹¹⁴⁸ Zabell also argues that statements made by examiners that “no latent prints have ever been found to match the rolled print of a different person” to be misleading, as no systematic search for such pairs on an entire databank of millions of fingerprints has ever been performed.¹¹⁴⁹ A second misconception discovered in the case of *Havvard*, referred to above, was that the term “peer review” as a standard of measure in *Daubert*, was incorrectly used by crime laboratories who saw it as the comparison made by a second examiner (mostly a senior examiner or peer).¹¹⁵⁰ In *Daubert*, it refers to publications of papers in refereed scientific journals. The court in *Havvard* accepted the prosecution expert’s statement of a zero error rate in the method used.¹¹⁵¹ This claim was in contrast with results produced by the International Association for Identification on proficiency tests in 1995, showing the fallibility of fingerprint examiners.¹¹⁵² The federal circuit court of appeal gave an unqualified seal of approval to friction ridge impression evidence.

¹¹⁴⁶ Zabell SL “Fingerprint Evidence” 2005 (13) *J Law & Policy* 143: 169. (“It need hardly be said that mere courtroom use does not constitute validation”).

¹¹⁴⁷ Giannelli *Daubert Challenges* 2006.

¹¹⁴⁸ DNA Advisory Board Standard “Validation is a process by which a procedure is evaluated to determine its efficacy and reliability for forensic casework analysis and includes: (1) Developmental validation is the acquisition of test data and determination of conditions and limitations of a new or novel DNA methodology for use on forensic samples; (2) Internal validation is an accumulation of test data within the laboratory to demonstrate that established methods and procedures perform as expected in the laboratory”, 1998.

¹¹⁴⁹ Zabell *Fingerprint evidence* 2005 [170].

¹¹⁵⁰ *US. v. Havvard* 2001 [854].

¹¹⁵¹ *US. v. Havvard* 2001 [854].

¹¹⁵² Grieve D “Possession of Truth” 1996 *J Forensic Ident* 46:521-523. Also, Starts JE “Forensic Science on the Ropes: An Upper Cut to Fingerprinting” 1996 *20 Sci Sleuthing* 20(1).

7.5.2.5 Llera Plaza

During the time of appeal regarding the matter of Mitchell, in another case, *United States v. Llera Plaza*,¹¹⁵³ the court held that a fingerprint expert could not give an opinion that two sets of prints “matched” – that is, a positive identification to the exclusion of all other persons.¹¹⁵⁴ Judge Pollak took judicial notice in his first order of the uniqueness and permanency of fingerprints and accepted the theoretical basis of fingerprint identification. However, he held that the ACE-V method, used to arrive at match or non-match conclusions, did not meet the first three *Daubert* factors, and only met the general acceptance factor in the technical as opposed to the scientific community of fingerprint examiners. Judge Pollak ruled on January 7th, 2002, that examiners from both counsel could testify on examinations performed, but that they are precluded from testifying on the issue of match or non-match of fingerprints. The state then moved to reconsider and enlarge the record through the presentation of additional information. The motion was granted and both sides presented additional expert testimony in February 2002. On rehearing, Judge Pollak, changed his mind and reversed his earlier stance.¹¹⁵⁵ The change triggered a series of news reports¹¹⁵⁶, legal

¹¹⁵³ *U.S. v. Llera Plaza*, 179 F. Supp. 2d 492, 57 Fed. R. Evid. Serv. 983 (E.D. Pa. 2002), withdrawn from bound volume and opinion vacated and superseded on reconsideration, 188 F. Supp. 2d 549, 58 Fed. R. Evid. Serv. 1 (E.D. Pa. 2002).

¹¹⁵⁴ Kaye DH “The Non-science of Fingerprinting” 2003 *United States v. Llera Plaza Quinnipiac Law* 21:1073. (“The ruling sent shock waves through the community of fingerprint analysts, the FBI, and the Department of Justice”).

¹¹⁵⁵ Two factors led Judge Pollak to reconsider his ruling. One was expert testimony-some elicited from defense witnesses-indicating that, like the FBI, New Scotland Yard had moved to a non-numerical standard. A second factor was the judge's review of other, recent federal cases upholding the admission of nonscientific expert opinions despite their subjectivity. In the end, on the record before him, Judge Pollak concluded that “*there is no evidence that certified FBI fingerprint examiners present erroneous identification testimony, and ... there is no evidence that the rate of error of certified FBI fingerprint examiners is unacceptably high. With those findings in mind, I am not persuaded that courts should defer admission of testimony with respect to fingerprinting . . . until academic investigators financed by the National Institute of Justice have made substantial headway on a "verification and validation" research agenda. For the National Institute of Justice, or other institutions both public and private, to sponsor such research would be all to the good. But to postpone present in-court utilization of this "bedrock forensic identifier" pending such research would be to make the best the enemy of the good.*” *Llera Plaza*, 188 F. Supp.2d at 572.

¹¹⁵⁶ Specter M “Do Fingerprints Lie? The Gold Standard of Forensic Science is Now Being Challenged” 2002 *New Yorker* 96 (discussing case including interview with judge).

articles,^{1157,1158,1159,1160}, and scientific articles,^{1161,1162} with many commentators convinced that *Llera Plaza version 2* was less faithful to *Daubert* than *Llera Plaza version 1*.¹¹⁶³ On the counter side, Robert Epstein,¹¹⁶⁴ the Federal Defender in both the *Mitchell* and *Llera Plaza* case, wrote a paper promoting the success story of fingerprint evidence on trial. Another defence lawyer, Lisa Steele, provided a detailed analysis report¹¹⁶⁵ on both good and bad of fingerprint evidence after the trials.

During the second hearings of *Llera Plaza 2*, a fingerprint examiner from New Scotland Yard testified that the proficiency tests of the FBI were sub-standard and far too easy, hence the high proficiency grades.¹¹⁶⁶ During Judge Pollak's March 2002 *Llera Plaza 2* decision on "publications and peer review", he noted that none of the scientific books and other publications by scientists satisfy *Daubert's* prong because it was not peer reviewed. This was not received well at all by highly credentialed and respected scientists who published studies in refereed journals. Judge Pollak added that:

¹¹⁵⁷ Cole SA "Grandfathering Evidence: Fingerprint Admissibility Rulings from Jennings to Llera Plaza and Back Again" 2004 *Am Crm Law Rev* 41:1189. Also, Romandetti K "Recognizing and responding to a problem with the admissibility of fingerprint evidence under Daubert" 2004 *Jurimetrics J* 45:41. Also, La Marte TM "*Sleeping Gatekeepers: United States v. Llera Plaza* and the unreliability of forensic fingerprinting evidence under Daubert" 2003 *ALB Law J Sci & Tech* 14:71. See also, Sombat JM "Latent Justice: Daubert's impact on the evaluation of fingerprint identification testimony" 2002 *Fordham Law* 70:2819. Also, Benedict N "Fingerprints and the Daubert standard for admission of scientific evidence: Why fingerprints fail and a proposed remedy" 2004 *Ariz Law Rev* 46:519.

¹¹⁵⁸ Faigman DL "Is science different for lawyers?" 2002 *Science* 297: 339-340.

¹¹⁵⁹ Imwinkelried EJ "Fingerprint Science" 2002 *National Law J* 26:18-19.

¹¹⁶⁰ Saks MJ "The Legal and Scientific Evaluation of Forensic Science (Especially Fingerprint Expert Testimony)" 2003 *Setton Hall Law Rev* 33:1167-1187.

¹¹⁶¹ Cho A "Forensic science. Judge reverses decision on fingerprint evidence" 2002 *Science* 295(5563):2195-7.

¹¹⁶² Cho A "Forensic science. Fingerprinting doesn't hold up as a science in court" 2002 *Science* 295(5554):418.

¹¹⁶³ Mnookin JL "Fingerprints: Not a gold standard" 2003 *Sci & Tech* 47. ("Judge Pollak's first opinion [restricting latent fingerprint individualization testimony] was the better one"); Sombat, at 2825: ("[T]he results Judge Pollak reached when he excluded expert testimony concerning fingerprints [in *Llera Plaza 1*] was fair"); 2002 Recent Case 115 *Harv L Rev* 2349: 2352 ("Fingerprint expert testimony does not survive application of the Daubert factors").

¹¹⁶⁴ Epstein R "Fingerprints meet Daubert: The Myth of Fingerprint 'Science' is Revealed" 2002 *Southern California Law Rev* 75:605-655.

¹¹⁶⁵ Steele LJ "The Defense Challenge to Fingerprints" 2004 *Criminal Law Bulletin* 40(3):213-240.

¹¹⁶⁶ U.S. v. Llera Plaza, 2002 [558].

“[...] regarding the desirability of research to provide the scrutiny and independent verification of the scientific method to aid in assessing the reliability of fingerprint evidence, that such efforts would be “all to the good. But to postpone present in-court utilization of this ‘bedrock forensic identifier’ pending such research would be to make the best the enemy of the good.”¹¹⁶⁷

On April 29th, 2004, two years after the *Llera Plaza* judgment, Mitchell appealed to the U.S. Court of Appeals for the Third Circuit.¹¹⁶⁸ Circuit Judge Becker upheld Mitchell’s conviction, as well as Judge Joyner’s conclusion that fingerprinting evidence was admissible. The review court, however, held that Judge Joyner improperly took judicial notice of the uniqueness and permanency aspects of fingerprints. The appeal court did agree on the ground that the discipline satisfied the *Daubert* validity factors. On the issue whether the discipline is a science, the court observed that it was unnecessary to draw a distinction between scientific and non-scientific expert testimony based on the 1999 U.S. Supreme Court decision in *Kumho Tire* (discussed in Chapter 8 of this thesis).¹¹⁶⁹ The gatekeeper role of the trial judge in keeping unreliable opinion evidence out of the court applied to expert opinions, whether deemed to be scientific-, technical, or experience-based. The court continued to discuss each of the *Daubert* factors and their applicability to the case at hand.

The first factor to consider was whether the premises on which fingerprint identification relies, are testable and tested. The court concurred with the premises that friction ridge arrangements were unique and permanent, and that positive identification can be made from fingerprints with sufficient quantity and quality of characteristics. They based their conclusion on three tests conducted by the FBI:

- A comparison test of 50,000 left-sloped patterns against 50,000 sets of ten prints, a process involving 2.5 billion comparisons on the AFIS computer system, with no matches of prints coming from different digits.
- Tests performed involving identical twins, again with no matches between identical twins.

¹¹⁶⁷ *U.S. v. Llera Plaza*, 2002 [558-549].

¹¹⁶⁸ *United States v. Mitchell*, 365 F.3d 215 (3rd Cir. 2004), cert. denied S. Ct. 446 (2004).

¹¹⁶⁹ *Kumho Tire Co. v. Carmichael*, 526 U.S. 137 (1999).

- The FBI survey that showed no state identification bureaux had ever encountered two different sources with the same fingerprint.

The court was, however, troubled by the fact that the FBI abandoned the number of minutiae required for a positive identification and that they relied on an “unspecified, subjective, sliding scale mix of quality and quantity of detail”. It was irrelevant, however, because in the Mitchell’s case, 14 minutiae points were identified with level 2 detail, which was higher than the required numeric approach in the past. The court concluded on this factor that the “hypotheses that undergird the discipline of fingerprint identification is testable, if only to a lesser extent actually tested by experience.”¹¹⁷⁰

With regard to the second factor on peer review, the court indicated its dissatisfaction with the state’s argument that the verification step of ACE-V constitutes effective peer review. The court concluded that “when looking at the entire picture, the ACE-V verification step may not be peer review in its best form, but on balance, the peer review factor does favor admission of friction ridge comparisons and individualizations.”¹¹⁷¹

The third factor relates to error rate. The court distinguished between two error rates: false positives (identify a wrong individual to the unknown print) and false negatives (exclude a person of interest when enough detail exists to make the identification). The defence emphasised error on false negatives where practitioners did not make an identification where they should have made one. The court felt that it should be of concern for law enforcement policy, but for the courtroom, the rate of false negatives is immaterial to the *Daubert* admissibility of fingerprint identification. The court would be more concerned about false positive rates. The court hence concluded that “where what is sought to be proved is essentially a negative (i.e., the absence of false positives) it seems quite appropriate to us to use a burden-shifting framework”. The burden of producing contrary evidence shifted to the defence, when the state witness testified that he was unaware of significant false

¹¹⁷⁰ *U.S. v. Mitchell* 365 F.3d 215 (3d Cir. 2004), [1013a].

¹¹⁷¹ *U.S. v. Mitchell* 365 F.3d 215 (3d Cir. 2004), [161a].

positive identifications. The court was convinced that the method of estimating false positive error rates would be very low, if quantified.

On the fourth factor on the maintenance of standards, the court found the procedural standards of ACE-V lacking in some measure, and not favourable for admitting fingerprint evidence.

On the fifth and final factor regarding the general acceptance criteria, the court found these to favour the admitting of the fingerprint evidence.

7.5.2.6 *Brandon Mayfield*

On March 11, 2004, the dynamics in fingerprint identification changed again, despite years of successes and accomplishments, when another fingerprint misidentification scenario played out on an international level. Terrorists detonated bombs on several commuter trains in Madrid, Spain, killing 191 and injured more than 1,400 others.¹¹⁷² The Spanish National Police recovered a bag of detonators connected with the attacks and transmitted them to Interpol with a request that the FBI provide assistance in identifying any fingerprint evidence. On March 19th, the FBI laboratory identified a print to Brandon Mayfield, a Portland Lawyer, as the source of the crime scene print on the bag. Mayfield's prints were one of twenty candidate prints from an AFIS search conducted on the latent comparison search. A side-by-side comparison revealed Mayfield as the source of the crime scene print. The conclusion was verified by a second examiner at the FBI and reviewed by the unit chief.

On further investigation, the FBI learned that Mayfield was a Muslim, married to an Egyptian immigrant, had represented a convicted terrorist in a child custody dispute in Portland, and had contacts with suspected terrorists. On May 6, the FBI obtained a material witness warrant and a criminal search warrant. Mayfield was arrested, brought before the court and his request for home detention was denied. He was incarcerated at the Multnomah County Detention Center in Portland, Oregon.

¹¹⁷² Office of the Inspector General Oversight and Review Division, *A Review of the FBI's Handling of the Brandon Mayfield Case*, March 2006.

On May 17th, the Court appointed an independent fingerprint examiner to review the FBI's fingerprint identification, who, after two days, concurred with the identification. On the same day, the Spanish National Police positively identified the same crime scene print with Ouhane Daoud, an Algerian national. On May 20th, Brandon Mayfield was released from detention after 15 days since his incarceration. He was placed under house detention. After receiving the evidence from the Spanish authorities, the FBI withdrew its identification of Mayfield on May 24th, and the government dismissed the material witness proceeding.

The FBI immediately started with a corrective action process and on June 4th, convened a 2-day session with an International Panel of fingerprint experts. Several panelists concluded that the initial examiner failed to conduct a complete analysis before conducting the IAFIS search of the crime scene print. Other panelists ascribed the error to overconfidence in the power of IAFIS and the pressure of working on a high-profile case. Some panelists blamed contextual bias from the initial examiner's conclusion. The panel made recommendations, including documentation requirements and modified verification procedures.¹¹⁷³ The Inspector General report made additional recommendations to the FBI.¹¹⁷⁴ These included that the laboratory:

- develop criteria for the use of Level 3 details to support identifications;
- clarify the "one discrepancy rule" to assure that it is applied in a manner consistent with the level of certainty claimed for latent fingerprint identifications;
- require documentation of features observed in the latent fingerprint before the comparison phase to help prevent circular reasoning;
- adopt alternate procedures for blind verifications;
- prior cases in which the identification of a criminal suspect was made on the basis of only one latent fingerprint searched through IAFIS, and

¹¹⁷³ Robert B and Stacey "A Report on the Erroneous Fingerprint Individualization in the Madrid Train Bombing Case" 2004 *J Forensic Ident* 54:707. This is not to say that the report is not without problems. The report continued to employ the dichotomy between "methodological" and "human" error.

¹¹⁷⁴ Inspector General Report, 2006, [14].

- more meaningful and independent documentation of the causes of errors as part of the Laboratory's corrective action procedures is obtained.

In October 2004, attorneys for Mayfield filed a civil action against the FBI, DOJ, and several individuals. The case of Brandon Mayfield became a hot topic of interest in court cases and critics of fingerprint identification.^{1175,1176} Since 2004, no misidentifications were reported, which could be interpreted as no mistakes made by examiners or as possibly unknown misidentifications.

7.6 External factors influencing the credibility of fingerprint evidence

7.6.1 *The National Academy of Science (NAS) Report*

In the 2009 National Academy of Science (NAS) report, the NAS committee found that although fingerprint evidence has been used in court for more than 100 years, there was insufficient evidence to conclude that fingerprint comparison evidence is reliable.¹¹⁷⁷ The report also stated that fingerprint examination was not supported by “peer reviewed” published studies establishing its scientific basis and validity and that it lacks rigorous protocols to guide practitioners to a more subjective assessment of matching characteristics.¹¹⁷⁸ The report continued to state that the discipline lacks professional standards which make it difficult to determine with adequate reliability that the source that left the imperfect impression at the crime scene is similar to that of the print (ten print) on file.¹¹⁷⁹ In conclusion, the report dismissed the contention by some examiners that friction ridge analysis is not subject to possible error.¹¹⁸⁰

¹¹⁷⁵ Kershaw S “Spain and United States at Odds on Mistaken Terror Arrest” 2005-06-05 *New York Times*. (Spanish authorities cleared Brandon Mayfield and matched the fingerprints to an Algerian national); McRoberts F and Possley M “Report Blasts FBI Lab: Peer Pressure Led to False JD of Madrid Fingerprint” CHI TRIB Nov 14 2004, at I. The FBI found 15 “matching” points, while the Spanish examiners found only seven.

¹¹⁷⁶ Mnookin JL “The Achilles Heel of Fingerprints” 2004 in *Washington Post Washington A27*.

¹¹⁷⁷ NAS Report 2009.

¹¹⁷⁸ NAS Report 2009 [8].

¹¹⁷⁹ NAS Report 2009 [43].

¹¹⁸⁰ NAS Report 2009 [142].

The result of the report was received with mixed emotions^{1181,1182,1183} from those practising the discipline, and those opposing the use of the evidence. American courts received many motions to bar the prosecution from presenting evidence that a fingerprint specialist had determined that any latent print recovered from a crime scene matched known prints taken from defendants.¹¹⁸⁴ Numerous courts acknowledged the NAS report, but responded in its criticism in different ways.¹¹⁸⁵ Some courts heard the motions and did not add value to it in deliberations, while others grappled with its methods and more carefully considered its findings. Most courts kept on relying on the adversarial process (i.e., defence counsel's ability to weed out frailties in such evidence via cross examination) to resolve and neutralise any post-NAS report concerns about the reliability of fingerprint evidence.¹¹⁸⁶ Before several court hearings on the post –NAS report on fingerprints will be discussed, it is important to briefly consider the response of those guarding the discipline.

On August 3rd, 2009, SWGFAST posted their response to the NAS report.¹¹⁸⁷ The working group acknowledged and supported many of the conclusions and recommendations made by the NAS report, but also addressed some of the concerns expressed in the report. The working group accused the NAS report of inadequately reporting the significant body of constructive scientific research already conducted. The working group also reconfirmed its partnership with the NIST, NIJ and other recognised bodies on continuation of research to address the challenges highlighted in the NAS report. They also reconfirmed their continuous review of guidelines and standards for the examination of friction ridge impressions. The SWGFAST working group expressed their concern that the NAS report may be used to misrepresent the true state of the practice and science on friction ridge comparisons. It stated that it would be unfortunate if the report was represented as a definitive analysis of forensic science practices as opposed to a presentation of concerns derived

¹¹⁸¹ Editorial "Science in Court" 2010 *Nature* 464: 325.

¹¹⁸² Spinney L "The Fine Print" 2010 *Nature* 464: 344-346.

¹¹⁸³ Holden C "Forensic Science Needs a Major Overhaul, Panel Says" 2009 *Science* 323:1155.

¹¹⁸⁴ *United States of America v. Robert Abdul Baines* 573 F 3d 979 (10th Cir 2009) 981 (United States Court of Appeals, Tenth Circuit); Council (n 16); *United States of America v. David Brian Stone* 2012 WL 219435 (E D Mich) (United States District Court, East Division, Michigan).

¹¹⁸⁵ See

<http://www.wisprd.org/attachments/article/246/National%20Academy%20of%20Sciences%20Report%20Case%20List.pdf> (Date of use: 12 January 2019).

¹¹⁸⁶ Cooper SL "The Collision of Law and Science: American Court Responses to Developments in Forensic Science" 2013 *Pace Law Rev* 33(1):234-300.

¹¹⁸⁷ SWGFAST *Position summary* posted on 8/3/2009.

from a selective group of interviews and limited literature reviews. The working group also acknowledged that not all agencies applied the guidelines and standards recommended on their site in practice and urged them to comply with these recommendations.¹¹⁸⁸ The SWGFAST working group then addressed the following topics of concern:

“Subjectivity-

SWGFAST acknowledges that subjectivity is inherent in the friction ridge examination process. Subjectivity (informed judgment) is inherent to every human activity. Therefore, it naturally follows that it is also present in any scientific endeavor where the human is the instrument and the decision cannot be separated from the method. In fact, subjectivity is found in the informed analysis of DNA, a discipline the NAS regards throughout the report as the gold standard of forensic science. During the encoding phase of DNA entry to a search system, a human examiner subjectively determines the presence and the degree to which individual markers are present in the sample. Additionally, the examiner also compares peak heights of the unknown sample with known samples presented as likely candidates for a match, the quality of which can also sometimes vary in degraded samples. A great deal of subjectivity exists specifically in the interpretation of mixtures of DNA profiles and low copy number analysis. All of these factors point to the same subjective elements in the determination of the relevance of features in DNA analysis that are present in the selection and evaluation of friction ridge skin features.

Subjectivity allows for informed, educated conclusions based upon inductive reasoning supported by training, experience, and data obtained from scientific research. Without subjectivity, collective knowledge could not be applied to issues at hand in any endeavor, including legal decisions, medical diagnoses, and forensic casework. SWGFAST proposes that subjectivity is an inherent and necessary aspect of complex reasoning, and that the real issue at hand is that of transparency. At a minimum, transparency is necessary to better assess the work that is being performed and to provide those outside the profession with an understanding of the processes that are used.¹¹⁸⁹

Methodology-

The comparative examination of friction ridge skin is conducted pursuant to a method known by the acronym ACE-V (Analysis, Comparison, Evaluation, and Verification). ACE-V is a methodology that mirrors the vision science’s description of object recognition when applied to the examination of fingerprint impressions. It is a structured, logical procedure designed to minimize bias resulting in very few errors. Thorough documentation of this process allows for the transparency required for competent reviewers to determine that the data and case information have been appropriately considered. Additionally, blind verification can and is used as an ancillary component to the examination process, and,

¹¹⁸⁸ SWGFAST *Position summary* 2009 [3].

¹¹⁸⁹ SWGFAST *Position summary* 2009 [4].

when appropriate, is used to detect and guard against the possibility of bias or otherwise tainted results.¹¹⁹⁰

Error Rates-

SWGFAST acknowledges that errors do occur and furthermore that claims of zero error rate in the discipline are not scientifically plausible. Although current practices and procedures will not facilitate the calculation of error rates in actual casework because of varying factors and limited information, history demonstrates that the actual error rate in practice is very low. It may be possible to arrive at a generic error rate that considers methodological and practitioner errors through the use of an appropriately designed study. However, determining the reliability of the practice and not error rates would be a better metric in assessing its value as evidence. Billions of comparisons worldwide have occurred over the course of a century with an extremely low number of errors. Recent studies published in peer reviewed journals, although limited, also tend to suggest that the error rate of friction ridge examination, when conducted by competent examiners, is very low.¹¹⁹¹

Brandon Mayfield-

The misidentification of Oregon Attorney Brandon Mayfield as the source of a fingerprint found on a plastic bag containing bomb making parts in the Madrid train bombing of 2004 by FBI fingerprint examiners, is often presented as proof of the fallible nature of fingerprint examinations. This error has been used by advocates to dismiss the claims of reliability of fingerprint identification and illustrate the effects of bias on the process. Although unfortunate, the error prompted the FBI to re-examine its processes and to implement improved practices. The national and international fingerprint community has also addressed the error and has applauded the transparency demonstrated by the FBI as it analyzed the event. The fingerprint community credits the FBI's recommendations to improve the protocols, processes, and practices that further advance procedures and methods within the profession."¹¹⁹²

The SWGFAST working group concluded by making 12 recommendations to address other concerns within the NAS report.¹¹⁹³

The International Association for Identification, the largest professional body dealing with fingerprint identification, issued an immediate reaction to the NAS report.¹¹⁹⁴ The IAI aimed at putting its community at rest by referring to a specific sentence of the NAS report, "*it seems plausible that a careful comparison of two impressions can accurately discern whether or not they had a common source*" (emphasis added). Without denying the need for further research and policy, the IAI stressed the fact that fingerprint evidence shall be considered as reliable when delivered by trained

¹¹⁹⁰ SWGFAST *Position summary* 2009 [4].

¹¹⁹¹ SWGFAST *Position summary* 2009 [5].

¹¹⁹² SWGFAST *Position summary* 2009 [5].

¹¹⁹³ SWGFAST *Position summary* 2009 [5-8].

¹¹⁹⁴ International Association for Identification "Response to NAS Report" 2009-03-18 *Leahy*.

and competent examiners, following accepted practices and standards. The IAI furthermore issued a memorandum to its members, stating its support to many of the report's recommendations, cautioning against asserting "100% infallibility (zero error rate)" and advising its members not to state their conclusions in absolute terms when dealing with population issues.¹¹⁹⁵

The European Network of Forensic Science Institutes also reacted through its European fingerprint working group (ENFSI–EPWG) to the NAS report.¹¹⁹⁶ After recalling the different initiatives of the ENFSI–EPWG as well as Interpol that had addressed some of the points made in the report, it was agreed that the need for devoting careful attention to the way fingerprint evidence is reported¹¹⁹⁷ is important because such evidence should not be considered as absolute or factually sufficient in itself to exclude every donor in the world.

In the scholarly literature, critical attention was also given to how fingerprint evidence ought to be conveyed in court. Mnookin¹¹⁹⁸ insisted on the limitations of fingerprint research at the time of the NAS report and rightly clarified the key issue as follows:¹¹⁹⁹

"The problem with fingerprint evidence is not that it completely lacks probative power, but rather that research on the domain has not yet established the appropriate limits to its probative power, or shown how that value varies depending on its quality or its quantity of information".

¹¹⁹⁵ International Association for Identification: NAS memo" 2009-02-19 *Garreth R (President)*.

¹¹⁹⁶ Meuwly D "Position of the European Fingerprint Working Group (EFPWG) of the European Network of Forensic Science Institutes (ENFSI) Regarding the NRC report" 2011 *J Forensic Ident* 61:677–679.

¹¹⁹⁷ Meuwly *ENFSI* 2011 [678].

¹¹⁹⁸ Mnookin JL "The courts, the NAS, and the future of forensic science" 2010 *Brooklyn Law Rev.* 75:1209-1275.

¹¹⁹⁹ Mnookin 2010 [1240].

Mnookin called for a stricter regimen to testify to individualisation. The question of uniqueness and individualisation further attracted numerous commentaries,^{1200,1201,1202,1203,1204,1205,1206} as did the question of testifying in court.¹²⁰⁷

Acknowledging the outcry from the larger community on the term “individuation”, the SWGFAST in 2011 changed the wording on “*Individualization*” from their original 2002 version as follows:

- “2002 - Individualization occurs when a latent print examiner, trained to competency, determines that two friction ridge impressions originated from the same source, to the exclusion of all others’.¹²⁰⁸
- 2011 - Individualization is the decision by an examiner that there are sufficient features in agreement to conclude that two areas of friction ridge impressions originated from the same source. Individualization of an impression to one source is the decision that the likelihood the impression was made by another (different) source is so remote that it is considered as a practical impossibility’.¹²⁰⁹

The change in definition changed the strength of value of the evidence according to Cole,¹²¹⁰ as examiners now were required to move to a “decision”, rather than a “conclusion” or “determination”.

¹²⁰⁰ Kaye DH “Probability, individualization, and uniqueness in forensic science evidence: listening to the academics” 2010 *Brooklyn Law Rev* 75:1163–1185.

¹²⁰¹ Koehler JJ and Saks MJ “Individualization claims in forensic science: still unwarranted” 2010 *Brooklyn Law Rev* 75:1187–1208.

¹²⁰² Kaye DH “Beyond uniqueness: the birthday paradox, source attribution and individualization in forensic science testimony” 2013 *Law Probab Risk* 12: 3–11.

¹²⁰³ Cole SA “Who speaks for science? A response to the National Academy of Sciences report on forensic science” 2010 *Law Probab Risk* 9:25–46.

¹²⁰⁴ Cole SA and Roberts A “Certainty, individualization and the subjective nature of expert fingerprint evidence” 2012 *Criminal Law Rev* 824–849.

¹²⁰⁵ Cole SA “Individualization is dead, long live individualization! Reforms of reporting practices for fingerprint analysis in the United States” 2014 *Law Probab Risk* 13:117–150.

¹²⁰⁶ Page M, Taylor J and Blenkin M “Uniqueness in the forensic identification sciences--fact or fiction?” 2011 *Forensic Sci Int* 206:12–18.

¹²⁰⁷ Cole SA “Splitting hairs? Evaluating ‘Split Testimony’ as an approach to the problem of forensic expert evidence” 2011 *Sydney Law Rev* 33:459–485.

¹²⁰⁸ Scientific Working Group on Friction Ridge Analysis Study and Technology (SWGFAST). http://www.swgfast.org/documents/methodology_2002 (not available for public view anymore, archived; copy with author of thesis; can be made available on request).

¹²⁰⁹ Scientific Working Group on Friction Ridge Analysis Study and Technology (SWGFAST). http://www.swgfast.org/documents/examinations-conclusions/111026_Examinations-Conclusions_1.0.pdf (§ 4.3.2.2), 2011.

¹²¹⁰ Cole “Individualization is dead” 2014.

Cole also viewed the change as an improvement on transparency, because, indirectly, it affirmed for the first time that probabilities come into play in any fingerprint conclusion.

The SWGFAST also published “The Fingerprint Sourcebook”¹²¹¹ in 2011, with 15 chapters covering various subjects in fingerprint identification (history, anatomy and physiology, embryology and morphology, recording, classification, AFIS, development, preservation, examination, documentation, quality assurance, legal aspects, research, abilities and vulnerabilities). The book was not authored in a response to the NAS report, but because of the continuous criticism and the lack of an authoritative reference works.

In March 2011, Polski *et al.* published a report titled, “The Report of the International Association for Identification, Standardization II Committee”.¹²¹² The document provides an historical background of the work of the IAI Standardization Committee since 1970 to 2010. The report cites approximately 4000 references relating to forensic sciences, statistics, genetics, etc.¹²¹³ The committee recognised that there may still be additional relevant references beyond those gathered and commented on the two approaches followed by practitioners within the field to form an opinion during comparisons’, namely numeric and non-numeric approaches:¹²¹⁴

- A numeric approach primarily considers the number of corresponding friction ridge characteristics in the same relative position. While all details of the friction ridge impression are considered, a predetermined number of friction ridge characteristics are required before an opinion of identification can be effected. The numeric approach is also referred to as the Empirical Standard Approach.
- A non-numerical approach does not require a predetermined number of corresponding friction ridge characteristics before an opinion of identification can be effected. A non-

¹²¹¹ SWGFAST 2011 *The fingerprint sourcebook* Washington DC: US Department of Justice National Institute of Justice.

¹²¹² Polski J *et al.* “The Report of the International Association for Identification, Standardization II Committee” March 2011, *U.S. Department of Justice*.
<https://www.ncjrs.gov/pdffiles1/nij/grants/233980.pdf> (Date of use: 22 January 2020).

¹²¹³ Polski IAI report 2011 Appendix G [57-256].

¹²¹⁴ Polski IAI report 2011 Appendix C [47].

numeric approach considers additional discriminating features of the friction ridge skin, to include, but not limited to ridge edges, pore location, creases, absence of characteristics in a larger area, scarring, etc. The non-numeric approach is also referred to as the Holistic Approach.¹²¹⁵

The review highlighted the NAS report and predicted an increase in publications on psychological and cognitive processes involved in the ACE-V process, as well as in statistical research devoted to the field.

7.6.1.1 Legal proceedings after NAS report

The SWGFAST concern soon became reality with defence counsel using the NAS report as the foundation for their arguments of unreliability of fingerprint evidence. A number of law reviews and published articles highlighted key concepts mentioned in the NAS report and how courts dealt with motions to dismiss fingerprint evidence in courts.^{1216,1217,1218,1219,1220,1221,1222,1223}

The following section will briefly discuss selected court judgments referenced in the NAS report.

¹²¹⁵ Interpol European Expert Group on Fingerprint Identification I and II.

¹²¹⁶ Giannelli PC “The 2009 NAS forensic science report: a literature review” 2012 *Crim Law Bull* 48:378–393.

¹²¹⁷ Mnookin “Courts, the NAS, and the future” 2010.

¹²¹⁸ Kaye “Probability, individualization, and uniqueness” 2010.

¹²¹⁹ Koehler “Individualization claims” 2010.

¹²²⁰ Cole “Who speaks for science” 2010.

¹²²¹ Kaye D “Identification, individualization and uniqueness: what’s the difference?” 2009 *Law Probab Risk* 8:85–94.

¹²²² De Villiers W “Fingerprint comparison evidence has been under sustained attack in the United States of America for the last number of years: Is the critique with regard to reliability sufficiently penetrating to warrant the exclusion of this valuable evidence?” Bluris, LLB, LLD, Advocate of the High Court of South Africa, Associate Professor in the Department of Procedural Law, University of Pretoria, South Africa 2012 *Oxford University Commonwealth Law J* 12(2).

¹²²³ Cooper SL “Challenges to Fingerprint Identification Evidence: Why the Courts Need a New Approach to Finality” 2016 *Mithell Hamline Law Rev* 42(2):756-780.

In the case of *The People v. Michael John Lugo*,¹²²⁴ the defendant tried to exclude the prosecution's latent fingerprint evidence, and to present the evidence of an expert who challenged the reliability of fingerprint evidence based on the NAS report.

Another post-NAS report trial is that of *United States of America v. Robert Abdul Baines*,¹²²⁵ where the plaintiff, Robert Baines, was found guilty in a federal district court on five counts: conspiracy to possess cannabis with intent to distribute; possession of cannabis with intent to distribute; possessing a firearm in furtherance of a drug trafficking crime; possession of a firearm after former conviction of a felony; and possession of ammunition after former conviction of a felony. He was sentenced to 123 months' imprisonment. Fingerprint evidence played a crucial part in the conviction and Baines appealed the admissibility of the fingerprint evidence at the trial. Two latent prints were discovered on a magazine of one of two pistols in a vehicle pulled over at a border checkpoint. The vehicle transported marijuana, while Baines was travelling in a van behind the suspected vehicle. The two prints matched those of Baines. The defendant's motion invoked Rules 104(a) and 702 of the Federal Rules of Evidence and *Daubert v. Merrell Dow Pharm., Inc.*, 509 U.S. 579, 593-94, 113 S.Ct. 2786, 125 L.Ed.2d 469 (1993). The prosecution called two experts to the trial: Mr. Fullerton, the state-employed fingerprint examiner and FBI agent Meagher (who testified in *United States v. Mitchell*). Agent Meagher's testimony was comprehensive, explaining concepts underlying fingerprint identification, the ACE-V procedure followed by fingerprint examiners to respond to inquiries aimed at some of the factors suggested in *Daubert* as relevant to the consideration of expert testimony. He also explained the three levels of detail used during the comparison phase. When asked about error rates, he described two types of errors, practitioner error and methodological error. He testified that for the method, either no error or zero error can be assigned. He acknowledged that practitioners do make mistakes, but then asserted that the "practitioner error rate goes to the individual, not to the whole of the practitioners applying the methodology." It would be "inappropriate," he testified, to "take the accumulation of those who have made errors and assign it to those who have not made errors," thus at least implying that most practitioners have achieved a level of perfection that is rather rare, to say the least, in other

¹²²⁴ *The People v. Michael John Lugo* 2009 WL 2025637 (Cal App 2 Dist) item 13 (Court of Appeal, second District, Division 5, California).

¹²²⁵ *United States of America v. Robert Abdul Baines*, No. 08-2098, Decided: July 20, 2009.

complex human endeavors”. He cited one publication in which 92 participants performed a total of 5,861 individualisations, out of which there were only two errors, both of which were noticed and corrected by verifiers. In cross-examination, agent Meagher testified that the FBI had no statistical data on the calculation of error rates for their analysts, but that each analyst would know his or her error rate based on proficiency test results during initial training and annually after training. He assigned errors into three categories: false or mistaken identifications, missed identifications, and clerical errors. The first is the error of greatest concern for the court. Agent Meagher testified that the FBI had made on average about one erroneous identification (false positive) every 11 years. The total number of identifications made has been about one million per year, he continued, so that the known actual error rate was about one per eleven million identifications.¹²²⁶ Baines’ testimony was conceded by that of Mr. Fullerton of the New Mexico forensic laboratory. He identified 11 minutiae points of interest to that of the left thumb of Baines, but could not determine the pattern of the print based on its partiality.¹²²⁷ The defendant did not present any expert witnesses.

In the Court of Appeals, all the *Daubert* factors were considered:

- With regard to the first factor that the technique can be, and has been tested, the court found that although the record did not show that the testing would meet all the standards of science, the technique has been subject to testing in the world of criminal investigation and other practical applications. In law enforcement, fingerprint identification has been utilised by agencies all over the world for over a hundred years and the examiners are subject to demanding training and on-going proficiency examinations. Although the proficiency examinations had been criticised on several grounds, the court saw no basis on the record to totally disregard the proficiency tests.
- The court found that the first factor weighed somewhat in favour of admissibility, although not compellingly.

¹²²⁶ Baines 2009 [99].

¹²²⁷ Baines 2009 [23-24].

- With regard to the second factor, peer review and publication, the court found the defendant's argument that the verification stage of the ACE-V process doesn't constitute an independent peer review of true science, to be convincing. In accordance with this, the court found that the second factor did not favour admissibility.
- The third factor is the known or potential error rate of procedure. The court found that the evidence of error rate on record strongly supports a decision to admit the evidence of the fingerprint examiner.
- The fourth factor is the existence and maintenance of standards controlling the process. The court indicated that it could find very little evidence of standards that guide and limit the analyst in the execution of his duties. Critical steps in the process depended on the subjective judgement of the analyst. However, the court added that subjectivity does not preclude a finding of reliability. The court assumed for argument's sake that this factor did not support admission.
- The fifth factor addresses the question whether the technique has gained general acceptance in the relevant scientific or expert community. The defendant contended that fingerprint analysis has not been accepted in any unbiased scientific or technical community. The court, while acknowledging that unbiased experts would carry greater weight, held that the overwhelming acceptance by other experts in the field should also be considered.¹²²⁸

The court subsequently found that, on the whole, fingerprint analysis evidence is suitably reliable for admission. This was another victory for the fingerprint community, although a number of problems still had to be addressed.

In the 2007 *State of Maryland v. Rose* case, a trial judge excluded the fingerprint evidence because of a perceived insufficiency to support the findings of the latent print examiner.¹²²⁹ In 2009, the U.S. District Court in *U.S. v. Rose*, ruled the same fingerprint evidence admissible without the need for a *Daubert* hearing.¹²³⁰ Brian Rose challenged the admissibility of fingerprint evidence that linked

¹²²⁸ Baines 2009 [990-992].

¹²²⁹ *State of Maryland v. Rose*, Baltimore Cty. Cir. Ct., K06-0545, Oct. 19, 2007.

¹²³⁰ *United States v. Rose*, USDC D.Md, Crim. CCB-08-0149, 2009.

him to a fatal carjacking. The court ruled that precedent – the general acceptance of the ACE-V method in the fingerprint science community – and the lack of evidence to contradict the conclusion that misidentifications were extremely rare, favoured admission. The court stated that vigorous cross-examination, presentation of contrary evidence, and careful instruction on the burden of proof are the appropriate methods of challenging perceived flaws in admissible scientific or technical evidence.¹²³¹

In 2010, the Supreme Court of Massachusetts considered the NAS Report in more detail in *Commonwealth v. Gambora*.¹²³² A jury convicted the defendant, Jesus Gambora, of murder in the first degree of Jaya Desai, on theories of deliberate premeditation and felony-murder, unlawful possession of a firearm, possession of ammunition without a firearm identification card, and eleven indictments charging armed robbery on April 19th, 2003. One of Gambora's appeals related to the claim that the evidence of fingerprint identification, and particularly evidence that a latent print could be "individualised" to a particular person, was inadmissible under *Daubert v. Merrell Dow Pharms*.¹²³³ and *Commonwealth v. Lanigan*,¹²³⁴ on the ground that its underlying scientific or technical reliability had not been established, and at the time had been showing to have no currently demonstrable scientific or technical basis.¹²³⁵

The judge denied the motion without a hearing, ruling that:

"The ACE-V methodology was generally accepted within the fingerprint-examiner community, and citing *Commonwealth v. Patterson*, a case in which this court concluded that consistent with the decisions of other courts that have considered the issue since *Daubert*, ... the underlying theory and process of latent fingerprint identification, and the ACE-V methodology in particular, are sufficiently reliable to admit expert opinion testimony regarding the matching of a latent impression with a full fingerprint."¹²³⁶

¹²³¹ Rose 2009 [724–25] (citing *United States v. Crisp*, 324 F.3d 264, [268–70] (4th Cir. 2003)).

¹²³² *Commonwealth v. Gambora*, 933 N.E.2d 50 (2010).

¹²³³ *Daubert* 1993 [579].

¹²³⁴ *Commonwealth v. Lanigan*, 419 Mass. 15 (1994).

¹²³⁵ *Gambora* 2010 [721].

¹²³⁶ *Gambora* 2010 [628].

It was also noted by the judge that the NAS report does not conclude that fingerprint evidence is so unreliable that courts should no longer admit it. The report does not appear to question the underlying theory which grounds fingerprint identification evidence; but as the report states, there is scientific evidence supporting the theory that fingerprints are unique to each person and do not change over a person's life.¹²³⁷

In *United States v. Love*,¹²³⁸ the U.S. District Court in California acknowledged that the forensic science community has started to take steps to respond to the findings of the NAS report.

Although many defendants relied on the NAS report to bolster their appeals and motions, arguing that the report supported that fingerprint identification evidence was unreliable and should not have been admitted against them, courts largely rejected such challenges, relying on the adversary process.¹²³⁹ In *Gambora*, the court noted the confusion from the NAS Report by stating:

“As our discussion of the NAS Report reflects, there is tension in the report between its assessments that, on the one hand, “it seems plausible that a careful comparison of two impressions can accurately discern whether or not they had a common source,” but that, on the other, “merely following the steps of ACE-V does not imply that one is proceeding in a scientific manner or producing reliable results.”¹²⁴⁰

The exoneration of Lana Canen in November 2012, was another blow to fingerprint evidence. Lana Canen was released from jail after spending 7 years of a 55 year murder conviction in Elkhart, Indina.¹²⁴¹ On Thanksgiving Day in 2002, Helen Sailor, a blind 94 year-old woman was brutally slain in her Waterfall High Rise apartment complex. Two years later, Canen and Andrew Royer were charged with the killing of Sailor. The only evidence that connected Canen to the crime scene

¹²³⁷ *Gambora* 2010 [725].

¹²³⁸ *United States v. Love*, a U.S. No. 10cr2418-MMM, 2011 WL 2173644 (S.D. Cal. June 1, 2011), at 8. District Court in California recognized that the NAS Report criticized some aspects of fingerprint analysis, but denied Love's challenge to the admission of fingerprint evidence against him. The court based its conclusion, in part, on precedent and on evidence that “the forensic science community generally . . . ha[s] begun to take appropriate steps to respond to [the] criticism [contained in the NAS Report].”

¹²³⁹ Cooper “Collision of Law and Science” 2013.

¹²⁴⁰ *Gambora*, 933 N.E.2d at 61 n.22 (citing NAS Report [142]).

¹²⁴¹ *Canen v. State*, 860 N.E.2d 591 (Ind. 2006).

was a latent print on a pill bottle left behind at the scene. Detective Dennis Chapman, who was only trained on ten prints, made an erroneous level one connection to the little finger of Canen. In spite of his lack of training and qualification, Chapman was allowed to testify during the 2005 trial, matching Canen's left little finger to the latent print on the pill container. The defence attorney retained Charles Lambdin, a retired police detective, who looked at the prints for thirty minutes and concluded some similarities, and Canen as a possible source of the print. The attorney did not seek a pre-trial deposition of Chapman, nor did he move to exclude his testimony overstating his testimony. After being denied several direct appeals, in August 2009, Canen filed a petition for state post-conviction relief (pcr).¹²⁴² This time, Canen's attorney retained Kathleen Bright-Birnbaum, a certified latent fingerprint expert, who excluded Canen as the source of the latent print. Chapman was requested to re-examine the evidence and concluded that he had erred in his previous finding. He admitted that additional training after the 2006 trial, as well as gaining more experience on comparisons, led to his changed opinion. He explained when he had referred to experience and training during the trial he was referring to "known" or "inked" prints and not latent prints.¹²⁴³ Canen's conviction was vacated and she was released in 2012. She filed a civil action against Detective Chapman for violating her right to due process under *Brady v. Maryland*,¹²⁴⁴ when he proclaimed to be an expert in fingerprint identification without any latent fingerprint examination experience. The court found that:

"On cross-motions for summary judgment, the district court granted judgment in favor of Detective Chapman. The court expressed "doubts" as to whether Detective Chapman's inexperience was "suppressed for purposes of Brady" because the evidence was potentially "available to [Ms.] Canen through the exercise of reasonable diligence." The district court did not resolve that issue, however, because it believed that, in any event, Detective Chapman was immune from suit".¹²⁴⁵

¹²⁴² Indiana Post-Conviction Relief Rule 1.

¹²⁴³ Canen 2006 [32–33].

¹²⁴⁴ *Brady v. Maryland*, 373 U.S. 83 (1963).

¹²⁴⁵ United States Court of Appeals, Seventh Circuit. Lana Canen, *Plaintiff-Appellant*, v. *Dennis Chapman*, in his individual capacity as Deputy for the Elkhart County Sheriff Department, Defendant-Appellee. No. 16-1621 Decided: January 27, 2017.

Defendants continued with their motions for dismissal of forensic fingerprint evidence during trials,¹²⁴⁶ but cases reported after 2012 demonstrate the influence of “finality” on judicial decision making. Finality is a theoretical reason for courts to restrict any post-conviction review. Finality was first detailed by Professor Paul Bator in an article, titled “Finality in Criminal Law and Federal Habeas Corpus for State Prisoners.”¹²⁴⁷ Bator argues that “the finality of criminal judgments serves important interests that are harmed by expansions of post-trial rights” and proposes that, “because we can never be 100 percent certain that no error of law or fact was made during trial (or appellate) proceedings, we must impose an end to litigation at some point or else the case could conceivably go on *ad infinitum*”.¹²⁴⁸ When judges consider appeals, they must balance society’s interests in finality against the rights of defendants.¹²⁴⁹

7.6.2 OSAC Sub-committee on pattern evidence

Similar to sub-committees for Seized Drugs and DNA, the Friction ridge subcommittee was also established in February 2014. The committee consisted of practitioners, academia, statisticians, and other subject matter experts. The working policies and procedures previously under the auspices of SWGFAST were transferred and placed under the OSAC subcommittee, as discipline-specific baseline documents.¹²⁵⁰ The subcommittee also divided into smaller task groups working on various topics to ensure best practices for practitioners within the criminal justice system. Due to past challenges as a non-traditional science, compared to chemistry and biology, pattern evidence task groups have a challenging road to get documents approved through the OSAC registry. A number of documents are either in work in progress or have been forwarded to the next level for approval. The working documents cover best practices, standards and training within the

¹²⁴⁶ *State v. Sheehan*, 273 P.3d 417, 422–23 (Utah Ct. App. 2012). Also, *United States v. Stone*, 848 F. Supp. 2d 714, 716 (E.D. Mich. 2012). Also, *Gee v. United States*, 54 A.3d 1249, 1253 (D.C. 2012). 136. *Id.* at 1262. Also, *People v. Luna*, 989 N.E.2d 655, 659 (Ill. App. Ct. 2013), appeal denied, 996 N.E.2d 20 (Ill. 2013).

¹²⁴⁷ Bator P “Finality in criminal law and Federal Hebeas Corcup for state prisoners” 1963 *Harvard Law Rev* 76(3):451–453.

¹²⁴⁸ P Popko SG “Putting Finality in Perspective: Collateral Review of Criminal Judgments in the DNA” 2011 *Law J Soc Just*: 75-76.

¹²⁴⁹ Kim “Beyond finality” 2013.

¹²⁵⁰ National Institute of Standards, Forensic Science, Friction Ridge Subcommittee. <https://www.nist.gov/topics/forensic-science/friction-ridge-subcommittee> (Date of use: 26 September 2019).

discipline of friction ridge examinations. Since their establishment, no documents have yet been taken up into the OSAC registry.

7.6.3 PCAST

Seven years after the NAS report, featured-comparison methods, which include fingerprint comparisons, received another blow when the President's Council of Advisors on Science and Technology (PCAST) released its latest report to the President, "Forensic Science in Criminal Courts: Ensuring Scientific Validity of Feature-Comparison Methods",¹²⁵¹ on September 20th 2016.¹²⁵² Fingerprint identification as a comparison method was again under attack.

The PCAST committee criticised the lack of studies to assess error rates and that the lack of empirical testing indicated a serious weakness in the scientific "culture" of forensic science.¹²⁵³ The committee did, however, commend the FBI's efforts to perform empirical studies ("Black Box" studies) to assess foundational validity and measure reliability after the 2009 NAS report. Again, the subjective decision process applied through the ACE-V was criticised and recommendations were made to promote efforts towards an objective process. The committee also iterated concern on the verification process, which is not "blind" (second examiner should not have any information regarding the first examiner's decision process for identification).¹²⁵⁴ Again, the single misidentified case of Mayfield in 2004 appeared in the report, despite the fact that a full investigation and rectification were implemented since the incident had occurred, as discussed earlier by the FBI, to avoid similar mistakes. The committee acknowledged the SWGFAST document "Standards for examining friction ridge impressions and resulting conclusions (Latent/Tenprint)", published in September 2011, as a step in a more objective direction. The committee also referenced the studies of Evett and Williams (1996), Langenburg (2009), Langenburg *et al.* (2012), Tangen *et al.* (2011), FBI, and Pacheco *et al.* (2014) and made the following conclusions:

¹²⁵¹ PCAST *Report* 2016.

¹²⁵² PCAST *Report* 2016.

¹²⁵³ PCAST *Report* 2016 [87].

¹²⁵⁴ PCAST *Report* 2016 [90].

- Collectively, the studies demonstrate that many examiners can, under “some” circumstances, produce correct answers at “some” level of accuracy.
- The empirically estimated false positive rates are “much higher” than the general public believe they were.

Other concerns mentioned by the committee were directed to cognitive bias and the lack of available data for blind proficiency tests.¹²⁵⁵

The PCAST report ignited a series of responses from various national and international forensic organisations.¹²⁵⁶ These acknowledged some research shortcomings, but the majority criticised the oversight and unsupported statements made by the committee.^{1257,1258}

¹²⁵⁵ PCAST *Report* 2016 [100-101].

¹²⁵⁶ See Public comments to PCAST report 2016

https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/PCAST/pcast_forensics_2016_public_comments.pdf (Date of use: 12 January 2019).

¹²⁵⁷ FBI statement, 20 September 2016: “[T]he FBI disagrees with many of the scientific assertions and conclusions of the report. The report makes broad, unsupported assertions regarding science and forensic science practice. For example, the report states that “the only way” to establish “validity as applied” is through proficiency testing, and requires a measurement of how often the examiner gets the correct answer, which is fundamentally at odds with a report of the National Academy of Sciences. The report also creates its own criteria for scientific validity and then proceeds to apply these tests to seven forensic science disciplines, failing to provide scientific support that these criteria are well accepted within the scientific community. The report does not mention numerous published research studies which seem to meet PCAST’s criteria for appropriately designed studies providing support for foundational validity. That omission discredits the PCAST report as a thorough evaluation of scientific validity. The report ignores important differences between forensic science disciplines, conflating fundamental differences between class-level and identification-level evidence, leading to troubling generalized conclusions about all forensic science disciplines.”

¹²⁵⁸ OSAC Friction Ridge Subcommittee, 14 December 2016: “If the PCAST maintains such emphasis on black box testing as the only means of establishing validity, the forensic science community could be inundated with predominantly black box testing and potentially detract from progress on understanding and refining other foundational aspects of the method, such as those previously outlined by the OSAC FRS, in an effort to identify ways in which to emphasize objective methods over subjective methods.” (see <https://www.nist.gov/topics/forensic-science/osac-researchdevelopment-needs>) (Date of use: 16 December 2019). The OSAC FRS notes that the PCAST appears to discount or otherwise disregard the role of “experience” and “judgment” in subjective feature-comparison methods. While the OSAC FRS does value empirical testing as hierarchically greater than experience and judgment, they do play an important role and should not be disregarded in their entirety. The disregard for experience and judgment is reminiscent of what was initially proposed by the Evidence Based Medicine (EBM) movement in the early 1990s. Cohen et al. (2004) in the context of medicine, cautions that experience and judgment remain important elements, especially in situations in which the circumstances of a particular case is underrepresented by empirical tests. (See Cohen *et al.*, “A Categorization and Analysis of the

The 18th Interpol International Forensic Science Managers Symposium report, released in 2016, reported very active research in the field of impression evidence, especially fingerprint detection and classification for forensic purposes.¹²⁵⁹ More than 280 papers were published regarding fingerprints between July 2013 and July 2016, in comparison to the 119 reviewed by the PCAST committee.¹²⁶⁰ It is unclear whether the PCAST committee found the majority of the published research irrelevant or did not know about the rest of the research conducted during the previous three years. The Interpol report stated that the combination of the Statistical and Applied Mathematical Sciences Institute, (SAMSI), PCAST and OSAC, under the auspices of the NIST and the NIJ, together with the work of the U.S. National Commission on Forensic Science (NCFS), pointed to a range of non-coordinated efforts into the analysis and assessment of the state of affairs of fingerprint analyses.¹²⁶¹

In December 2016, the Friction Ridge Subcommittee (FRS) of OSAC responded to the PCAST report.¹²⁶² The FRS committee agreed with PCAST on the need for standardised practices, foundational research and a formalised research agenda. The OSAC FRS committee agreed that additional research was needed to build upon an established body of knowledge, but disagreed on statements made where prior research efforts should be disregarded or discounted. The OSAC FRS also disagreed on the statement made by PCAST that black box studies are the only means of establishing foundational validity for subjective feature-based methods and with the absence thereof, subjective feature-comparison methods may be considered non-scientifically valid.¹²⁶³ The committee believed it is a one-dimensional approach and will detract from progress in other

Criticisms of Evidence Based Medicine". The human examiner will continue to serve as a critical, albeit subjective, element of the broader methodology. Rather than entire substitution, the human examiner and the measurement instrument will need to work complementary to one another. This is how science of all sorts is practiced.

¹²⁵⁹ Interpol 2016 [617].

¹²⁶⁰ PCAST 2016 [96-103].

¹²⁶¹ Interpol 2016 [618].

¹²⁶² OSAC letter to PCAST "Response to call for additional references" 2016-12-14.

https://www.nist.gov/sites/default/files/documents/2016/12/16/osac_friction_ridge_subcommittees_response_to_the_presidents_council_of_advisors_on_science_and_technologys_pcast_request_for_additional_references_-_submitted_december_14_2016.pdf (Date of use: 9 September 2019).

¹²⁶³ PCAST Report 2016 [66].

foundational aspects of the method. A third point of concern by the committee was the fact that PCAST discounted the role of experience and judgement in subjective feature-comparison methods, while the discipline believes that they play an integral part in the comparison process. The committee referenced the research of Cohen *et al.*,¹²⁶⁴ emphasising the importance of experience and judgement in the medical field and how it can be applied in subjective feature examination. The principle behind the argument is not to ban the knowledge gained and assessments made on the basis of experience and judgement, but rather to distinguish the source of the knowledge and transparently report the basis and associated limitations. The OSAC FRS also disagreed on the approach of the PCAST in deriving the high error rate from various studies and pointed out some mistakes made by PCAST during their calculations. Lastly, the subcommittee challenged the PCAST statement on the need to replace all subjective methods with objective methods.¹²⁶⁵ The argument the subcommittee made is that objective methods will never fully replace the subjectivity of the human examiner, as the examiner will continue to serve as a critical, albeit subjective element of the larger methodology. The examiner and measurement instrumentation will continue to complement each other in this discipline, and in any other scientific practice.

The next section will consider both sides of the argument on the impact of human influence in friction ridge examination.

7.6.4 *Human factors and fingerprint evidence*

As predicted by the 14th Interpol review paper,¹²⁶⁶ attention was directed to human factors in fingerprint analysis. Misidentifications were all constituted to human error and not methodological error. In the first of a series of published research, Tangen *et al.*¹²⁶⁷ discovered with a controlled fingerprint matching experiment (where the ground truth is known) that trained practitioners had a

¹²⁶⁴ Cohen et al "A Categorization and Analysis of the Criticisms of Evidence Based Medicine" 2004 *Int J Med Informatics* 73:35-43.

¹²⁶⁵ PCAST Report 2016 [47].

¹²⁶⁶ Interpol European Expert Group on Fingerprint Identification I and II, 2004.

¹²⁶⁷ Tangen JM *et al.* "Identifying fingerprint expertise" 2011 *Psychol Sci* 22:995–997. Also, Thompson MB *et al.* "Expertise in Fingerprint Identification" 2013 *J Forensic Sci* 58(6):1519- 1530.

0.68 % false positive rate compared to a 55.18 % rate for lay persons. Practitioners had a 7.88 % false negative rate. A follow-up study by Thompson *et al.*,¹²⁶⁸ involving a similar study, but using real crime scene prints (uncertain ground truth), practitioners had a 1.65 % false positive rate compared to a 55.73 % for lay persons. Practitioners in this study displayed a 27.81 % false negative rate. In a third study, Ulery *et al.*¹²⁶⁹ indicated that trained practitioners reported a 0.1 % false positive rate with controlled fingerprint matching, with a 7.5 % false negative rate. The results strongly supported the value of trained practitioners in fingerprint comparisons in the courtroom. With low error rates like these, criminal justice systems and judges may have confidence in *Daubert* hearings and trials where they rely on fingerprint evidence for convictions and pleas. In all of the papers referred to directly above, the authors convincingly demonstrate that trained examiners can clearly discriminate between prints that matched and those that do not, with a small margin of error.

In 2012, the “Expert Working Group on Human Factors in Latent Print Analysis” was sponsored by the National Institute of Standards and Technology and the National Institute of Justice to investigate human factors in latent fingerprint identification. The focus was on human error rates during fingerprint examinations, and one of their recommendations was the following:

“Examiners should be familiar with human factors issues such as fatigue, bias, cognitive and perceptual influences, and not state that errors are inherently impossible or that a method inherently has a zero error rate. Management should foster a culture in which it is understood that some human error is inevitable and that a comprehensive testing program of competency and proficiency should be developed and implemented.”¹²⁷⁰

Speaking generally, and taking the lead from medical and aviation research, the authors advocated that fingerprint identification would benefit from the human factors research and systems

¹²⁶⁸ Thompson MB *et al.* “Human Matching Performance of Genuine Crime Scene Latent Fingerprints” 2014 *Law and Human Behavior* 38(1):84-93.

¹²⁶⁹ Bradford T *et al.* “Accuracy and reliability of forensic latent fingerprint decisions” 2011 *PNAS* 108(19):7733–7738. www.pnas.org/cgi/doi/10.1073/pnas.1018707108 (Date of use: 03 January 2019). Also, Ulery BT *et al.* “Repeatability and reproducibility of decisions by latent fingerprint examiners” 2012 7(3) e32800 *PLoS ONE*.

¹²⁷⁰ Matthew B *et al.* “Human Matching Performance of Genuine Crime Scene Latent Fingerprints” 2014 *Law & Hum Behav* 38:84-85.

approaches to improve quality and productivity, and reduce the likelihood and consequences of human error.¹²⁷¹

The group also noted that research into fingerprint identification was well underway. For example, researchers have investigated the effect of contextual bias on fingerprint examiners,^{1272,1273,1274,1275,1276} the special abilities and vulnerabilities of fingerprint examiners,¹²⁷⁷ the psychophysics of fingerprint identification,¹²⁷⁸ the effect of technology,^{1279,1280} and statistical models of fingerprint identification.^{1281,1282 1283}

In 2014, Pacheco *et al.*¹²⁸⁴ from the Miami-Dade Police Department (MDPD), published a DOJ-funded research paper studying the reliability of the ACE-V process. The aim of the study was to report on an empirical evaluation of the reliability of ACE methodology used by latent examiners. The study used 109 latent print examiners across the United States and provided them with 80 latent prints with varying quality and quantity of information from ten known sources. The study yielded 5,963 sufficiency determinations, 4,536 ACE decisions, 532 ACE-V decisions, 1,311

¹²⁷¹ Matthew “Human matching” 2014 [2].

¹²⁷² Dror IE and Cole SA “The vision in ‘blind’ justice: Expert perception, judgment, and visual cognition in forensic pattern recognition” 2010 *Psychonomic Bulletin & Rev* 17(2):161-167.

¹²⁷³ Dror IE and Rosenthal R “Meta-analytically quantifying the reliability and biasability of forensic experts” 2008 *J Forensic Sci* 53(4):900-903.

¹²⁷⁴ Dror IE “On proper research and understanding of the interplay between bias and decision outcomes” 2009 *Forensic Sci Int* 191(1-3):17-18.

¹²⁷⁵ Dror IE *et al.* “Cognitive issues in fingerprint analysis: Inter- and intra-expert consistency and the effect of a ‘target’ comparison” 2011 *Forensic Sci Int* 208:10-17.

¹²⁷⁶ Langenburg G *et al.* “Testing for potential contextual bias effects during the Verification stage of the ACE-V methodology when conducting fingerprint comparisons” 2009 *J Forensic Sci* 54(3):571-582.

¹²⁷⁷ Busey TA *et al.* “Consistency and variability among latent print examiners as revealed by eye tracking methodologies” 2011 *J Forensic Ident* 61(1):60-91.

¹²⁷⁸ Vokey JR *et al.* “On the preliminary psychophysics of fingerprint identification” 2009 *Quarterly J Experimental Psychol* 62(5):1023-1040.

¹²⁷⁹ Dror “The use of technology” 2010.

¹²⁸⁰ Dror IE *et al.* “The impact of human-technology cooperation and distributed cognition in forensic science: biasing effects of AFIS contextual information on human experts” 2012 *J Forensic Sci* 57(2):343-52.

¹²⁸¹ Champod “Probabilistic approach” 2001.

¹²⁸² Neumann C *et al.* “Quantifying the weight of evidence from a forensic fingerprint comparison: a new paradigm” 2012 *J Royal Stat Soc Series* 175(2):371-415.

¹²⁸³ Neumann “Computation of likelihood ratios” 2007.

¹²⁸⁴ Pacheco I *et al.* “Miami-Dade Research Study for the Reliability of the ACE-V Process: Accuracy & Precision in Latent Fingerprint Examinations” 2014.

repeatability decisions, 326 ACE decisions under biased conditions, and 333 repeatability decisions under biased conditions. The study took into account inconclusive responses in determining error rates and established a false positive rate of 3.0 % and a false negative rate of 7.5 % for ACE examinations, and a false positive rate of 0.0 % and a false negative rate of 2.9 % for ACE-V examinations. This study was in contradiction to previous studies with low error rates, and although not published as a peer review article, it attracted attention from PCAST,¹²⁸⁵ Canada,¹²⁸⁶ OSAC,¹²⁸⁷ and statisticians.¹²⁸⁸ All of the aforementioned disagreed on the statistical calculations of the false positive and false negative rates encountered in the original study.

A questionnaire study conducted by Lieberman *et al.*¹²⁸⁹ on how different evidence types affects jury verdicts, reveals interesting results on forensic evidence and how it is perceived by jurors and students. With scenario changes, the position of evidence and type of information given the value of the evidence changed dramatically.

Leo's study¹²⁹⁰ on the words "subjective" and "objective" in relation to their use in various court cases, demonstrated equally interesting results.

7.6.5 European Network of Forensic Science Institutes

The ENFSI fingerprint working group published in 2016 its best practice manual.¹²⁹¹ This document will assist laboratories in harmonising their procedures and increasing consistency

¹²⁸⁵ PCAST *Report* 2016.

¹²⁸⁶ Wilkinson D *et al.* "Expert Fingerprint Testimony Post-PCAST - A Canadian Case Study" 2018 *J Forensic Ident* 68(3):299-331.

¹²⁸⁷ OSAC Friction Ridge Subcommittee. 2016. "Response to the President's Council of Advisors on Science and Technology's (PCAST) request for additional references".

¹²⁸⁸ Ausdemore M *et al.* "Review of several false positive error rate estimates for latent fingerprint examination proposed based on the 2014 Miami Dade Police Department study". Department of Mathematics and Statistics South Dakota State University.

¹²⁸⁹ Lieberman JD *et al.* "Gold Versus Platinum - Do Jurors Recognize the Superiority and Limitations of DNA Evidence Compared to Other Types of Forensic Evidence?" 2008 *Psychol Public Policy and Law* 14:27-62.

¹²⁹⁰ Leo W "Subjective- the misused word" 2008 *J Forensic Ident* 58:6-13.

¹²⁹¹ ENFSI "Best Practice Manual for Fingerprint Examination" *ENFSI-BPM-FIN-01 Version 01 - November 2015*.

among European laboratories, especially at a time when accreditation will soon be mandatory at the EU level. The manual provides a framework of procedures, quality principles, training processes and approaches to forensic examinations. It allows for harmonised methodologies with a recognition of the results of laboratory activities across jurisdictions.

7.6.6 AAAS

The American Association for the Advancement of Science (AAAS) summarised the problem in friction ridge examination into six specific questions in a quality and gap analysis assessment,¹²⁹² conducted in 2017:

- Is there an adequate scientific foundation for understanding the degree of variability of fingerprints: (a) among unrelated individuals; and (b) among relatives?
- Is there an adequate scientific foundation for understanding the degree of variability among prints made by the same finger: (a) on different surfaces, under different environmental conditions; and (b) over time as a person ages or is subject to injury?
- Is there an adequate scientific foundation for understanding the accuracy of automated fingerprint identification systems (AFIS)?
- Is there an adequate scientific foundation for understanding the potential for contextual bias in latent print analysis and how might it be addressed?
- Is there an adequate scientific foundation for understanding the accuracy of human fingerprint examiners and how their accuracy is affected by: (a) level of training and experience; (b) individual differences in perceptual ability; (c) analytic procedures and standards of practice; (d) quality control and quality assurance procedures; and (e) the quality of prints? If not, what kinds of research are needed to improve understanding of these issues?
- In light of the existing scientific literature, what kind of statements might fingerprint examiners reasonably make in reports and testimony in order to appropriately convey both the strength and uncertainty associated with fingerprint evidence?

¹²⁹² American Association for the Advancement of Science (AAAS) "Forensic Science Assessments, A quality and gap analysis, Latent fingerprint examination" September 2017.

These questions will be addressed in chapter nine, as part of the discussion on future developments required to improve friction ridge evidence in the criminal justice system.

7.7 Future developments within fingerprint evidence

Friction ridge evidence is one of the oldest forensic evidence used within the criminal justice system. In this chapter, a number of scientific and legal challenges, successes, and failures have been discussed. Although the discipline overcame many of the challenges, not all questions about its validity have been answered during this time. The following key aspects still require attention, based on past experiences:

- The scientific foundation to understand the degree of variability of fingerprints among unrelated individuals and among relatives.
- The scientific foundation to understand the degree of variability among prints made by the same finger on different surfaces, under different environmental conditions, and over time as a person ages or is subject to injury.
- The scientific foundation to understand the accuracy of databases.
- The scientific foundation to understand cognitive bias as a systematic error in human decision making and judgement.
- The scientific foundation to understand contextual bias in latent print analysis.
- The scientific foundation to understand the accuracy of fingerprint examiners and how the accuracy is influenced by:
 - o Level of training and experience
 - o Differences in perceptual ability
 - o Analytical procedures and standard practices
 - o Quality control and quality assurance
 - o Quality of the prints to be compared
- Accreditation, certification, quality control and validation should be mandatory in each crime laboratory and not a financial and administrative burden.
- Legal professionals, judges and juries should be educated on basic concepts and language used within friction ridge examination and the value of the evidence.

- Standardisation entities, such as OSAC and ENFSI, should continue with research and development processes and the implementation of national and international standards.

7.7.1 Variability of fingerprints

Fingerprint ridge variability is the longest researched topic within this discipline. A vast amount of articles have been published during the last century, within forensic science and within the medical field, to validate the scientific foundation of the variability to distinguish individuals. However, scientific literature indicates low likelihoods of individuals sharing a large number of common features, but not an adequate basis for assessing the rarity of a particular feature, or sets of features found in a print.¹²⁹³

The amount of matching features and the types of features necessary to establish the potential donor pool to a single source provide for some uncertainty. This uncertainty supports the inadequate scientific foundation towards individuality when examiners draw definitive conclusions. Although the AAAS recommended research on the frequency on individual fingerprint characteristics in various human populations to reduce the uncertainty, pattern distribution and frequencies of features continue to show no distinguished differences between populations to provide probative value to the evidence.¹²⁹⁴ Research by Gutierrez *et al.* (2007, 2011), for example, did find evidence of statistical differences in a Spanish population in the distribution of minutiae types between genders and the interrelation between fingers.^{1295,1296}

More research is necessary to provide qualitative methods for the estimation of probative value or weight of fingerprint evidence in criminal proceedings.

¹²⁹³ Nagar A *et al.* "Evidential value of automated latent fingerprint comparison: An empirical approach" 2012 *IEEE Transactions on Information Forensics and Security* 7(6):1752-1765.

¹²⁹⁴ Chen Y and Jain AK "Beyond Minutiae: A fingerprint individuality model with pattern, ridge and pore features, in advances in biometrics" 2009 *Third International Conference, ICB 2009. LNCS 5558, M. Tistarelli and M.S. Nixon, Eds. Berlin- Heidelberg: Springer Verlag, 523-533.*

¹²⁹⁵ Gutiérrez E *et al.* "Biological variability of the minutiae in the fingerprints of a sample of the Spanish population" 2007 *Forensic Sci Int* 172(2-3):98-105.

¹²⁹⁶ Gutiérrez-Redomero E *et al.* "Distribution of the Minutiae in the Fingerprints of a Sample of the Spanish Population" 2011 *Forensic Sci Int* 208(1-3):79-90.

7.7.2 *Variability of latent prints made by the same source*

Again, there is a body of research that supports the foundation on the amount of variation possible in latent prints during deposition on various substrates.^{1297,1298,1299,1300,1301} There will never be a perfect agreement between two prints from the same source, because of the elasticity of friction ridge skin.¹³⁰² It is important for examiners to understand friction ridge source to latent print variability to determine accurately whether a given difference between print comparisons was caused by distortion or actually reflects a difference in the underlying ridge patterns. Comprehensive training is needed within training modules to emphasise reasons between dissimilarities or differences due to variances caused by, for example, deposition pressure, distortion, etc.

The lack of proper training can lead to inconsistency between examiners, which will increase error rates in decision-making. This was highlighted through black box studies and contributed to a higher than expected false negative error rate.^{1303,1304} The PCAST and AAAS called for more similar studies to get a deeper understanding of the subjective decision making processes of experts.

7.7.3 *The accuracy of databases*

The development and growth of automated systems were discussed earlier in this chapter. The algorithmic application for comparison is not known by the larger scientific community due to the

¹²⁹⁷ Cappelli R et al. "Modelling plastic distortion in fingerprint images" In: *Advances in pattern recognition* 2001 ICAPR. (Singh S, Murshed N and Kropatsch W eds Vol 2013: 371-378).

¹²⁹⁸ Maceo AV "Qualitative Assessment of Skin Deformation: A Pilot Study" 2009 *J Forensic Ident* 59(4):390-440.

¹²⁹⁹ Sheets HD *et al.* "Distortion in fingerprints: A statistical investigation using shape measurement tools" 2014 *J Forensic Sci* 59(4):1113-1120.

¹³⁰⁰ Kalka ND and Hicklin RA "On relative distortion in fingerprint comparison" 2014 *Forensic Sci Int* 244:78-84.

¹³⁰¹ Fagert M and Morris K "Quantifying the limits of fingerprint variability" 2015 *Forensic Sci Int* 254:87-99.

¹³⁰² Expert Working Group on Human Factors in Latent Print Analysis. "Latent print examination and human factors: Improving the practice through a systems approach" 2012 *US Department of Commerce National Institute of Standards and Technology* 8.

¹³⁰³ Bradford T "Accuracy and reliability" 2011.

¹³⁰⁴ Ulery "Repeatability and reproducibility" 2012.

sensitivity of information kept on these databases, as it should be. However, the NIST plays an integral part regarding the success of the accuracy of databases through periodic evaluations of the systems.¹³⁰⁵ In 2011, Moses¹³⁰⁶ postulated that “automatic fingerprint-matching algorithms are significantly less accurate than a well-trained forensic expert.” The accuracy of any database is determined by the quality of the data that is uploaded. If the fingerprint quality is sub-standard, then good matches will be unlikely. The NIST developed a quantitative measure-of-quality tool¹³⁰⁷ for ten-prints of known sources, but a quantitative measure-of-quality tool is lacking for latent prints. Some researchers^{1308,1309,1310} made attempts to create such a tool, but more work is needed in this area. Until such a tool is designed to accurately compare latent prints to ten-prints objectively, the discipline has to rely on well trained human observations.

7.7.4 Systematic error in human decision making

It has been determined that judgements or decisions made by experts are influenced by irrelevant or inappropriate information.^{1311,1312,1313,1314} This is particularly of concern during any subjective decision-making process. There are a couple of ways for crime laboratories to prevent too much information reaching the expert before any decision making is performed. The expert should not

¹³⁰⁵ National Institute of Standards and Technology, <http://www.nist.gov/itl/iad/ig/fingerprint.cfm> (Date of use: 30 September 2019).

¹³⁰⁶ Moses K “Automatic Fingerprint Identification Systems (AFIS)” in Chapter 6 *The Fingerprint Sourcebook* McRoberts A Ed (US Department of Justice Office of Justice Programs NCJ 225320 2011).

¹³⁰⁷ NIST, http://www.nist.gov/itl/iad/ig/bio_quality.cfm (Date of use: 30 September 2019).

¹³⁰⁸ Hicklin RA *et al.* “Latent fingerprint quality: A survey of examiners” 2011 *J Forensic Ident* 61(4):385-418. Also, As the PCAST report noted (PCAST 2016 [97]), promising work in this area has been done by Hicklin *et al.* (2013), who developed what they call the Latent Quality Assessment Software (LQAS), a tool for evaluating the clarity of prints; and by researchers at the University of Lausanne, who are developing a quality metric and statistical assessment tool for latent prints that they call the Picture Annotation System (PiAnoS) <https://ips-labs.unil.ch/pianos/> (Date of use: 12 September 2017).

¹³⁰⁹ Yoon S *et al.* “LFIQ: Latent fingerprint image quality. Biometrics: Theory, Applications and Systems (BTAS)” 2013 *IEEE Sixth International Conference on Biometrics Compendium* 1-8.

¹³¹⁰ Kellman PJ *et al.* “Forensic comparison and matching of fingerprints: using quantitative image measures for estimating error rates through understanding and predicting difficulty” 2014 *PLoS ONE* 9(5):1-14.

¹³¹¹ Dror IE and Charlton D “Why experts make errors” 2006 *J Forensic Ident* 56:600–616.

¹³¹² Dror IE *et al.* “Contextual information renders experts vulnerable to making erroneous identifications” 2006 *Forensic Sci Int* 156:174–178.

¹³¹³ Dror “Meta-Analytically” 2008.

¹³¹⁴ Expert Working Group on Human Factors in Latent Print Analysis, 2012.

be exposed to the ten-print of the suspect before looking at the latent.¹³¹⁵ Context management procedures or policies should be implemented to minimise the amount of information that would reach the examiner prior to any examinations.^{1316,1317,1318,1319} The FBI already adopted such procedures for latent print analysis.¹³²⁰ Context management procedures or policies should form part of the quality management system and be audited appropriately.

7.7.5 *The accuracy of human fingerprint examiners*

Latent fingerprint examination has been performed by examiners for more than a century, but assessing the accuracy of examiners is a fairly recent practice.^{1321,1322,1323,1324,1325} The studies showed false identifications as low as 0 to 2.6 % and false exclusions from 2.9 % to 28 %. The data retrieved showed that latent fingerprint analyses are repeatable, reproducible, and accurate.¹³²⁶ For the court, the emphasis should be on whether the expert has applied the method properly.¹³²⁷ The AAAS has drawn three conclusions from accuracy studies:

¹³¹⁵ Dror IE *et al.* "Context management toolbox: A linear sequential unmasking (LSU) approach for minimizing cognitive bias in forensic decision making" 2015 *J Forensic Sci* 60(4):1111-1112.

¹³¹⁶ Cole SA "Forensic Science Reform: Out of the Laboratory and into the Crime Scene" 2013 *Texas Law Review* 91:123-136.

¹³¹⁷ Found B and Ganas J "The management of domain irrelevant context information in forensic handwriting examination casework" 2013 *Sci & Justice* 53(2):154-158.

¹³¹⁸ Stoel RD *et al.* "Minimizing contextual bias in forensic casework" In: *Forensic science and the administration of justice: critical issues and directions* Strom KJ and Hickman MJ eds (Sage Publications 2014) 67-86.

¹³¹⁹ Thompson WC "What role should investigative facts play in the evaluation of scientific evidence?" 2011 *Australian J Forensic Sci* 4(2-3):123-134.

¹³²⁰ Office of the Inspector General U.S. Department of Justice. (2006). A Review of the FBI's Handling of the Brandon Mayfield Case. Office of the Inspector General, U.S. Department of Justice, Washington DC, [1–330].

¹³²¹ Kellman "Forensic comparison and matching" 2014.

¹³²² Langenburg G *et al.* "Informing the judgements of fingerprint analysts using quality metric and statistical assessment tools" 2012 *Forensic Sci Int* 219:183-198.

¹³²³ Pacheco "Miami-Dade research study" 2014.

¹³²⁴ Thompson "Human matching performance" 2014.

¹³²⁵ Ulery "Accuracy and reliability" 2011.

¹³²⁶ PCAST 2016 [4].

¹³²⁷ The PCAST report suggests that its concept of "foundational validity" corresponds to the legal requirement in Rule 702(c) of the Federal Rules of Evidence that the expert testimony be the "product of reliable principles and methods," while the concept of "validity as applied" corresponds to the legal requirement in Rule 702(d) that "the expert has reliably applied the principles and methods to the facts of the case."

- Performance improves with training;^{1328,1329,1330}
- Performance varies depending on the difficulty of the comparison;^{1331,1332,1333} and
- Performance varies across examiners^{1334,1335}

Some criticism draws attention to the fact that the error rates observed through these research studies do not reflect the rate of error in actual practice.^{1336,1337,1338} The limitation of the studies is that the examiners know about being tested, similar to proficiency testing and tend to make additional efforts to enhance their performance.¹³³⁹ Examiners may lower their threshold for decision making, which might be higher during actual practice. The best way to overcome this problem is through “blind proficiency” testing, where proficiency tests are assigned to experts not knowing that it is a black box study or proficiency test. This will require good communication between law enforcement and laboratory/quality managers. It will also require the ten-prints of the “fake suspect” on the local or national database. Similar exercises have been conducted in DNA analysis, but these require a lot of time and are expensive.¹³⁴⁰ Blind proficiency testing should also be managed under the auspices of quality management and be part of certification programs.

¹³²⁸ Langenburg “Informing the judgements of fingerprint” 2012.

¹³²⁹ Tangen “Identifying fingerprint expertise” 2011.

¹³³⁰ Thompson “Expertise in fingerprint identification” 2013.

¹³³¹ Langenburg “Judgements of fingerprint analysts” 2012.

¹³³² Thompson “Human matching performance” 2014.

¹³³³ Kellman “Forensic comparison and matching” 2014.

¹³³⁴ Ulery *et al.* 2014, 2016

¹³³⁵ Hicklin RA *et al.* “Assessing the clarity of friction ridge impressions” 2013 *Forensic Sci Int* 226(1):106-117.

¹³³⁶ Haber RN and Haber L “Experimental results of fingerprint comparison validity and reliability: A review and critical analysis” 2014 *Sci & Justice* 54(5):375-389.

¹³³⁷ Thompson “Human Matching” 2014.

¹³³⁸ Koehler JJ “Intuitive error rate estimates for the forensic sciences” 2016 *Jurimetrics* 57(2):153-168. Available at SSRN: <https://ssrn.com/abstract=2817443> or <http://dx.doi.org/10.2139/ssrn.2817443> (Date of use: 19 December 2019).

¹³³⁹ Informing someone that they are being tested can create what psychologists call “demand characteristics” that change the person’s responses (Orne, 1962). Individuals who know they are being tested may shift their threshold of decision in ways designed to make them look good (Paulhus, 1991). Hence, performance testing provides a more realistic picture of human performance if the participants do not know they are being tested.

¹³⁴⁰ Peterson JL *et al.* “The feasibility of external blind DNA proficiency testing: Background and findings” 2003 *J Forensic Sci* 48(1):21-31.

7.7.6 Mandatory accreditation and certification for latent print examiners

The number of certified latent examiners in comparison with those who practice in the field is alarmingly low. Although studies discussed earlier show little difference in how certified and uncertified examiners perform on “black box” studies, it is always beneficial for the examiner who can show independent endorsement of their skills and knowledge on the subject matter. Investing in certification provides additional value to the examiner being an expert in the discipline. Certification entities also provide additional support to ensure certified examiners stay current and also abreast on changes and challenges within the discipline. Crime laboratory directors should follow the lead taken by the Texas Forensic Science Commission and implement mandatory accreditation of their laboratory and certification for all their examiners.

7.7.7 Uniform language for testimony and reports for friction ridge analysis.

Latent print examiners’ claim of identifying the source of a latent print with a 100 % accuracy during the first half of the 20th century, has cost the discipline dearly. Over time, external entities in the larger science community disputed the claim and argued that the statement had no scientific basis to limit the source to an individual. Early attempts by the SWGFAST and the DOJ, for example, to add language that acknowledged an element of uncertainty, provided a first step in the right direction, but were also criticised for not dealing with the level of uncertainty.

Guidelines from ENFSI recommended using estimate of likelihood ratios, thus avoiding the need for an expert to decide sufficiency on similarities and dissimilarities to justify a categorical conclusion. However, it does require the expert to make subjective estimates of the probability of the observed data under alternative hypotheses about the source of the prints. Such judgments are unknown on their reliability and accuracy.

The only reliable source to use to generate quantitative estimates of the probative value of print comparisons, is AFIS. Although AFIS systems are not designed to provide such statistical measures, adding such features to the software might strengthen the probative value.

The DOJ announced an approved, uniform language for testimony and reports for the forensic latent print discipline, at the Annual American Academy of Forensic Sciences in February 2018.¹³⁴¹ Even after the publication of the DOJ document on defining identification, the larger public and the AAAS criticised the language of “identification” as non-scientific, logical, or a linguistic difference, which will not make any difference to the lay person. In a recent paper, Simon Cole,¹³⁴² expresses concerns on the new language recommended by the DOJ, especially on the use of the categorical reporting term “identification”. Arguments on this topic will remain open until a real solution will surface, but for now, opposing sides will agree to disagree and will leave it to the court to decide on the value of the fingerprint evidence.

7.8 Conclusion

The claims of friction ridge evidence as a non-science or a pseudo-science hold no grounds. The validity and scientific foundation has been established within the field and the larger science community. Although more research is necessary to answer some scientific questions, other concepts have been proven with scientific certainty. The uniqueness and permanence of friction ridge detail per individual should not be questioned, unless two individuals show up in the future with the exact fingerprints.

The development of friction ridge patterns and the deposition of sweat residue has been well researched, outside the field of forensic science and the knowledge gained has been well applied within the discipline. Analytical approaches on the extraction of latent prints left behind at crime scenes on various substrates have also been explored and validated in various publications. More research is necessary to find the optimum extraction methods of prints for comparison, as the quality of the extracted print will determine the ease of decision making by the examiner.

¹³⁴¹ Press Release No. 18-213, Dep’t of Justice Office of Pub. Affairs, Justice Department Announces Plans to Advance Forensic Science 2018-02-21.

<https://www.justice.gov/opa/pr/justicedepartment-announces-plans-advance-forensic-science-0>,
<https://perma.cc/ZJ83-CJGY> (Date of use: 19 December 2019).

¹³⁴² Cole S “Discouraging Omen: A critical evaluation of the approved uniform language for testimony and reports for the forensic latent print discipline” 2018 *Legal studies research paper series No 2018-53 School of law University of California*.

The ACE-V methodology is well defined outside and inside the courtroom and, if applied correctly, will produce repeatable and reliable results during friction ridge examinations. Comparisons are not just confined to minutiae points that correspond between an unknown and a known print, but expand to multi-level comparisons and observations. It is, therefore, challenging to only quantify the number of minutiae points as a measure of identification. Many statistical models and approaches have been explored for probability values or likelihood ratios, but none of them received acknowledgement by the larger fingerprint community to apply in report writing or testimony.

Standardisation entities such as IAI, SWGFAST and OSAC developed helpful guidelines for practitioners to use and to apply in crime laboratories, although none of them are mandatory. The OSAC subcommittee has a daunting task to successfully publish improved standards on the OSAC registry, but great progress has been made from the previous SWGFAST documentation.

Legal challenges exposing the validity of the science delivered successes for both counsel. A large number of case law highlight the strengths and weaknesses of fingerprint evidence and the admissibility thereof, in criminal proceedings. Both the examiner, through FRE 702, and the evidence, through *Daubert* hearings, have been challenged on a root level. As discussed in this chapter, the discipline was exposed as fallible in the *McKie* and *Mayfield* cases, but mistakes were assessed and rectified immediately. However, more work needs to be done on examiner performance measures to ensure that similar mistakes are not made, only to be discovered years down the line through exonerations.

Automated systems increased in capacity and processing search speed. The quality of algorithms during auto-minutiae extraction should still be explored for improvements, as incorrect minutiae assignments should be limited during this process. It has been shown that human involvement in the process will be continuous until experts can totally rely on the software to perform such tasks.

A lot of ground has been gained on the language used in reporting and testimony. The one major change involved the moving from individualisation to identification (same source) reporting. The

discipline realised that through language, the value of evidence can be overstated or understated and more research in this regard is needed to quantify the language to provide a distinct value to fingerprint evidence.

Chapter 8 Firearm and Toolmark Examination

8.1 Introduction

The field of firearms and toolmarks in forensic science, traditionally known as ballistic examinations, belongs to the larger group of physics/pattern interpretation.¹³⁴³ The principles followed in this discipline are mainly those based on physics and to some extent, metallurgy. It is a study of marks left by the contact of two objects (mainly metals), with one being softer than the other. In firearm and toolmark examinations the firearm is considered the tool making the mark as it consists of the harder metal and the ammunition components are the work pieces as these contain the softer metal components.

This chapter will examine the foundational development underpinning the science of validity, reliability, and repeatability when comparing the tool as the transferring source of the markings to working pieces (projectiles and cartridge cases) found at the scene of a crime to those produced under controlled conditions (test fires). The chapter will also analyse instances where the law challenged the science, critically discuss entities influencing the science, as well as comment on future challenges to this area of forensic science. The critical review will allow the reader to understand the science that underpins forensic firearm and toolmark examination, as well as how the law challenged the physical science.

8.2 Principles of surface topography

In the process of firearm- and toolmarks, permanent changes in the topography of the surface are created. It is, therefore, possible for the forensic examiner to apply a microscopic test, to examine the transfer of marks from the hardened metal tool onto the softer work piece during contact.¹³⁴⁴

¹³⁴³ National Institute of Standards and Technology, Physics/Pattern Interpretation Scientific Area, <https://www.nist.gov/topics/forensic-science/physicspattern-interpretation-scientific-area-committee> (Date of use: 8 October 2019).

¹³⁴⁴ Monturo C *Forensic Firearm Examination* (Academic Press 2019).

Two types of transfer marks may be observed, namely impressed marks or striated marks. According to the glossary¹³⁴⁵ of the Association of Firearm and Toolmark Examiners (AFTE), the organisation which oversees the standard methodology used in firearm examinations, impressed toolmarks are caused when a tool, approximately perpendicular in action, forces with motion, a mark on the plane of the working piece. The forced action of the tool creates an inverse or reverse image of its own surface on the softer working piece. These marks are primarily visible on the breechface of the primer and cartridge case and the firing pin, leaving an impression. Striated toolmarks are contour variations, generally microscopic on the surface of the working piece, caused by a combination of force and motion where the motion of the tool is approximately parallel to the plane being marked. The parallel motion causes metal displacement on the softer working piece.¹³⁴⁶

Other terms used are friction marks, scratch marks or abrasion marks. The resulting marks can be classified, sub-classified and/or individualised based on certain characteristics. A combination of impressed and striated marks can be found on the projectile and on the cartridge case (known as the working piece). Firearms are manufactured in different ways that contribute to certain class characteristics and sub-class characteristics. It is important for the examiner to understand the dynamics of firearm mechanisms, manufacturing differences, optics of microscopy, and where to examine for transfer markings on projectiles and fired cartridge cases during comparisons.

8.3 Development of firearm and toolmark comparisons as a scientific methodology

Firearm and toolmark examination goes back to key discoveries made during the 19th century and 20th century. Table 8.1 captures the historical enhancements made in the discipline supporting the scientific foundation of the field of firearms and projectile identification.

¹³⁴⁵ The Association of Firearm and Toolmark Examiners (AFTE), AFTE Glossary Update, <https://afte.org/news/afte-glossary-update> (Date of use: 8 October 2019).

¹³⁴⁶ AFTE Glossary Update 2019.

Table 8.1 Firearm and toolmark discoveries

Discovery	Discoverer	Detail
Land and groove markings	Dr. Albert Llewellyn Hall, 1900	Dr Llewellyn Hall published an article, ¹³⁴⁷ titled “ <i>The Missile and the Weapon</i> ”. One of the topics in the article dealt with measurement of land and groove markings (impressions on the bearing surface of the bullet caused by the rifling process) made on bullets. He also discussed the examination of gunpowder residues in barrels of firearms.
Employed casting techniques	Alphonse Bertillon, 1900s	Bertillon employed casting techniques in the early 1900s for toolmarks discovered at crime scenes and utilised individual characteristics for the identification of tool source. ¹³⁴⁸
Recording the detail on the circumference of bullets	Richard Kockel, 1905	Kockel developed a technique for recording the detail on the circumference of bullets and tool marks. ¹³⁴⁹
Identify fired bullets to the firearm	Victor Balthazard, 1912	Balthazard invented a series of procedures to identify fired projectiles to the firearms from which they were fired. He took an elaborate series of photographs of test-fired projectiles from the firearm, as well as evidence projectiles. These photographs included the rifled areas of each land and groove. After enlarging the photographs, he and his staff carefully observed the markings and compared the uniqueness of the markings. Balthazard also applied these same specialised photographic techniques to the examination and identification of cartridge casings using firing pin, breechface, ejector and extractor marks. He published a series of articles on his

¹³⁴⁷ Hall A “The missile and the weapon” 1900 *AFTE J* 12(4):85-92. (This article was originally published in the *Buffalo Medical Journal* June 1900.

¹³⁴⁸ Goodefroy E “A process of ‘Moulage’ for reproducing marks indicative of forcible entry and molding those left by tools” 1932 *Am J Police Sci* 3:42-47

¹³⁴⁹ Kraft B “Critical review of forensic Ballistics, Part II” 1931 *Am J Police Sci* 2:52-56.

		discoveries in the early 1900s. ¹³⁵⁰ His work only started to influence American examiners in the 1920s. ¹³⁵¹
Estimation of distance from which a projectile was fired	Mr. Jorge T. Filho, 1921	Fiho published an article titled “Da Diagnose da Distancia nos Tiros de Projecteis Multiplos — Chumbo de Caca” (Estimation of distance from which a projectile was fired) while another thesis (author not identified) was titled, “Orificio de Entrada de Projecteis de Revolver — Estudo experimental das zonas de contorno nos tiros proximos” (Entrance wounds and Powder Markings). In the same year in Washington, D.C., Mr. Louis B. Wilson published an article, “Dispersion of Bullet Energy in Relation to Wound Effects”. ¹³⁵²
Microscopy of Small Arms Primers	Mr. Emile Monnin Chamot, 1922	Chamot authored a 61-page monograph titled, “The Microscopy of Small Arms Primers”. ¹³⁵³
Identification of Projectiles: Perfection of the Technique	Professor Balthazard, 1922	Balthazard published an article titled, “Identification des Projectiles: Perfectionnement de la Technique” (Identification of Projectiles: Perfection of the Technique) ¹³⁵⁴
	Mr. Georgiades, 1922	Georgiades published an article titled, “Une Nouvelle Methode pour Determiner l’Identite des Projectiles” (A

¹³⁵⁰ Balthazard V *De l’identification par les empreintes digitales* 1911. Also: Balthazard V “Identification des douilles de pistolets automatiques” (1913) *Archives d’Anthropologie Criminelle* 28. Also: Balthazard V “Identification de projectiles d’armes a feu” (1913) *Archives d’Anthropologie Criminelle* 28. Also: Balthazard V “Identification de projectiles” (1922) *Perfectionnement de la technique. Annales de Médecine légale* 2.

¹³⁵¹ Goddard C “Recent advances in forensic Ballistics” Proceedings of the 17th Annual Convention of the International Association for Identification July 20-24 1931: 104.

¹³⁵² Wilson LB “Dispersion of bullet energy in relation to wound effects” *The Washington* September 1921.

¹³⁵³ Chamot EM “The microscopy of small arms primers” 1922 Ithaca NY [Cornell publications ptg co]. <https://babel.hathitrust.org/cgi/pt?id=chi.087229635;view=1up;seq=11> (Date of use: 8 October 2019).

¹³⁵⁴ Balthazard V “Identification des projectiles: perfectionnement de la technique” January 1922 *Annales de Médecine Legale* 2:345-250.

		new method for determination of the identity of projectiles). ¹³⁵⁵
Communication on the Identification of Fired Bullets and Shells	Mr. DeRechter and Mr. Mage, 1922	DeRechter and Mage authored the article, "Communication sur l' Identification des Douilles et des Projectiles tires" (Communication on the Identification of Fired Bullets and Shells). ¹³⁵⁶
Firearms expertise	Dr. Wilfrid Derome, 1929	Derome authored a book titled, "Expertise en Armes a Feu" (Firearms expertise), that was globally accepted for its clarity and completeness. ¹³⁵⁷
Identification of Firearms from Ammunition Fired Therein	Jack D. Gunther, an attorney of the New York State Bar, and Charles O. Gunther, a Professor of Mathematics, 1935	These two authors published a book titled, "The Identification of Firearms from Ammunition Fired Therein". The book discusses principles of firearms identification and also advocates the need for science methodology in firearms identification. ¹³⁵⁸
Firearms Identification, Investigation & Evidence	Frank J. Jury and Jac Weller, 1957	Jury and Weller revised the textbook of Major General Julian S. Hatcher's "Firearms Identification, Investigation and Evidence". New material was added and original work updated in the new textbook. ¹³⁵⁹
Introduction to Toolmarks, Firearms and the Striagraph	John E. Davis, 1958	Davis was the author of a book, "An Introduction to Tool Marks, Firearms and the Striagraph". He provided more in-depth information on the examination and identification of firearms and tool-mark evidence. He also discussed the development of a new instrument, named the ' <i>Striagraph</i> '. He described the instrument as follows: "The Striagraph

¹³⁵⁵ Georgiades "Une nouvelle methode pour determiner l'Identite des projectiles" January 1922 *Annales de Medicine Legale Volume 2*: 30-32.

¹³⁵⁶ Hamby "The History of firearms" 1999.

¹³⁵⁷ Cimon D *et al.* "One hundred years of forensic sciences in Quebec: the evolution of scientific techniques since 1914" 2014 *Canadian Soc Forensic Sci J Vol 47 3*:148 -169.

¹³⁵⁸ Gunther JD and Charles O *The identification of firearms from ammunition fired therein* (NY: John Wiley and Son 1935).

¹³⁵⁹ Hatcher JS *et al.* *Firearms Investigation, Identification and Evidence* (Stackpole Company 1957).

		is primarily a measuring, tracing and recording device suited to the analysis of micro surface-contours, that is, to the detection of microscopic irregularities in surface smoothness”. The instrument never made it past the research stage, but provided information for the enhancement of advanced laser and digital imaging techniques. ¹³⁶⁰
Firearms Identification	Dr. J. H. Mathews, 1962	Mathews published a two-volume set of books, titled “Firearms Identification”. ¹³⁶¹
Firearms, the Law and Forensic Ballistics	Tom A. Warlow, 1996	Warlow authored a text on firearms identification titled, “Firearms, the Law and Forensic Ballistics”. It produced a useful text that contains excellent information for firearm and toolmark examiners.
Examining and Interpreting Forensic Evidence	Brian J. Heard, 1997	Heard is the author of a text on firearms identification titled, “Handbook of Firearms and Ballistics — Examining and Interpreting Forensic Evidence”. ¹³⁶²

In contrast to the other forensic disciplines discussed in this thesis, firearm and toolmark examinations do not require much instrumental or chemical developments for comparisons. The core of the science is built on the magnification of objects to observe and compare unique markings transferred from a tool (firearm) to objects (projectiles and cartridge cases). The path followed was to first recover test-fired projectiles (by discharging the firearm with similar ammunition into a water tank), as well as recovering ejected cartridge cases from the same firearm. The recovered projectiles and cartridge cases would then be taken to the laboratory for comparison to those projectiles and/or cartridge cases discovered on a crime scene.

¹³⁶⁰ Davis JE *An introduction to tool marks, firearms and the striagraph* (Charles & Thomas publishers 1958).

¹³⁶¹ Mathews JH *Firearms Identification* (volume I 2nd ed Charles C Thomas Publisher 1962).

¹³⁶² Heard BJ *Handbook of firearms and Ballistics: examining and interpreting* (Forensic Evidence 2nd ed Wiley 2008).

Before microscopic comparisons, examiners relied on photomicrograph comparisons to determine the identity of projectiles and/or cartridge cases. Microscopic comparisons were made possible through comparison microscopes. Professor Alexander von Inostranzeff was credited for his design of the first comparison device in 1885 to compare two small objects under an optical magnification system simultaneously. He claimed that to compare two objects with one microscope, one needs an excellent memory and could not rule out any risk of judgment error, especially if those objects had minor differences. He took two monocular microscopes and added one of them a “camera lucida”, a drawing device used at the time. By changing the position of the drawing device, he was able to obtain a simultaneous view of both comparison objects in both superimposed and split-image modes. However, the first comparison microscope came from the Optical Institute of Wilhelm and Heinrich Seibert in Wetzlar in 1911, later incorporated into the Ernst Leitz Company in 1917. It was the first microscope with dual illumination and imaging light paths as a comparison device.¹³⁶³ In 1925, Philip Gravelle designed a prototype comparison microscope dedicated for the examination of firearms. The first commercially available microscope for this purpose was manufactured by Spencer Lens Company in 1934.¹³⁶⁴ Since then, the features of the comparison microscope changed remarkably, but the concept remained the same. For more than a century, forensic toolmark examiners are using comparison microscopes in enhancing and comparing all projectile and cartridge evidence.

Over time, experts in the field developed internal training modules and large collection of images, which would later be compiled in textbooks for training purposes. The work of Dr Mathews, a firearm expert, needs mentioning. His first two books in 1962 were best sellers within the forensic community, and enclosed extensive reference materials that had been collected throughout his 40 year career as a firearm examiner and his subsequent years in retirement. Volume I¹³⁶⁵ consisted

¹³⁶³ Beck R “125 Years of comparison microscopy – from the ‘camera lucida’ to the automated comparison bridge” 2014-08-12 Leica Microsystems. <https://www.leica-microsystems.com/science-lab/forensics/125-years-of-comparison-microscopy-from-the-camera-lucida-to-the-automated-comparison-bridge/> (Date of use: 8 October 2019).

¹³⁶⁴ Dutton G “Firearm identification, comparison microscopes and the spencer lens company” 2002 *AFTE J* 34(2):186-198.

¹³⁶⁵ Mathews JH *Firearm Identification* (Volume I Charles C Thomas Publishers 1962). [http://index-of.co.uk/Tutorials2/Firearms%20Identification%20Volume%20I%20\(2nd%20Edition%201973\)%20By%20J%20Howard%20Mathews.pdf](http://index-of.co.uk/Tutorials2/Firearms%20Identification%20Volume%20I%20(2nd%20Edition%201973)%20By%20J%20Howard%20Mathews.pdf) (Date of use: 25 January 2020).

of information concerning the laboratory identification of a firearm, measurements of rifling data on a wide variety of handguns, and a series of appendices which include photographs of the firing pin impressions on rim fire cartridge cases. Volume II¹³⁶⁶ consisted of several hundred images of handguns to assist in their identification, illustrations of other handguns, and images of trademarks and other identification marks. Images of firearms generated were from Mathew's research, many were from his own collection, whilst others were borrowed from various sources, such as from firearm reference collections of numerous forensic (crime) laboratories, as well as private firearm collections. Volume III was published in 1973, after his death, and enclosed additional data on rifling characteristics, notes on less well-known American firearms, magnitude of original images and illustrations of firearms, and other reference materials.

To date, three types of microscopy were utilised in the comparison of the markings of firearm and toolmark evidence: optical microscopy (using a standard comparison microscope), comparison scanning electron microscopy (CSEM), and virtual microscopy. Over time, researchers^{1367,1368} had discovered that (1) traditional optical microscopy is the most practical and efficient way for comparisons; (2) CSEM is the most advanced technique, but is hardly used (high cost associated with the instrument and possibility of contamination if the instrument is also used for primer residue examination), and (3) vertical microscopy, still in early stages, but showing a lot of promise. Throughout the century, firearm evidence (work pieces) were examined microscopically to find valuable evidence that can be used during criminal investigations. It is therefore, important to know what examiners are looking at when applying the evidence to a microscopic examination.

¹³⁶⁶ Mathews JH *Firearm identification, Volume II: Original photographs and other illustrations of hand guns* (Charles C Thomas Publishers 2nd ed 1973).
https://archive.org/details/Firearms_Identification_Volume_II_2nd_Edition_1973_By_J_Howard_Mathews/mode/2up (Date of use: 25 January 2020).

¹³⁶⁷ Giverts P *et al.* "Inter-determination of three microscopic methods for examination of striae on polygonal bullets" 2013 *AFTE J* 45(1):48-51.

¹³⁶⁸ Scanlan MD and Reinholz AD "Scanning Electron Microscopy for Firearm and Toolmark Comparisons" 2013 *AFTE J* 45(1):43-47.

8.4 Fundamentals of comparisons

As previously stated, comparisons are based on the examination of unique markings transferred from the tool (firearm) to the working piece (projectile or cartridge), with the aim of determining the source relationship between the two. The comparison is not one dimensional, but consists of multiple variables on points of transfer. Interaction between the tool and the working pieces are not limited to one location. When performing a comparison, all areas of contact should be examined. Friction marks, abrasion marks, and scratch marks are terms commonly used when referring to striated marks. These marks contain class,¹³⁶⁹ sub-class^{1370,1371,1372} and/or individual¹³⁷³ characteristics of the tool as the source for producing the marks. With the variety of firearms and ammunition produced, it is of utmost importance for the examiner to be fully proficient in firearm mechanics, the cycle of operation, comprehensive notetaking (which will include microscopic operations and photography), and expert testimony.

The forensic examiner needs to acknowledge the variation in firearm manufacturing techniques and how it will impact the projectile and cartridge casing during the cycle of operation. Manufacturing machinery will contribute to tool surface roughness, chip formations, built up edges, plowing, side flow, shearing, chattering, grinding, and other tool wear. In addition, examiners should also consider milling, reaming, and broaching processes.

During the cycle of operation, the majority of the marks will be formed during each step when discharging the firearm. Each type of firearm potentially has unique contributions to every step,

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- ¹³⁶⁹ Class Characteristics “Measurable features of a specimen which indicate a restricted group source. They result from design factors and are determined prior to manufacture.” AFTE Glossary (2013).
- ¹³⁷⁰ Sub-class Characteristics “Features that may be produced during manufacture that are consistent among items fabricated by the same tool in the same approximate state of wear. These features are not determined prior to manufacture and are more restrictive than class characteristics.” AFTE Glossary (2013). Sub-class marks are shared by a subset of firearms of the same make and model. There is no distinctive subclass marks that allow them to be readily distinguished from individual marks.
- ¹³⁷¹ Lightstone L “The potential for and persistence of subclass characteristics on the breech faces of SW40VE Smith & Wesson Sigma pistols” 2010 *AFTE J* 42(4):308-322.
- ¹³⁷² Pauw-Vugts *et al.* “FAID2009: Proficiency test and workshop” 2013 *AFTE J* 45(2):115-127.
- ¹³⁷³ Individual Characteristics “marks produced by the random imperfections or irregularities of tool surfaces. These random imperfections or irregularities are produced incidental to manufacture and/or caused by use, corrosion, or damage. They are unique to that tool to the practical exclusion of all other tools.” AFTE *Glossary* (2013).

leaving class and individual characteristics. The cycle of operation in short consists of the following steps:

- *Feeding* the ammunition into a revolving chamber or magazine.
- *Chambering* of the cartridge (ensures a cartridge with specific dimensions fits in the chamber).
- *Locking* is the fixed and secured status of a bolt or breechblock with the chamber before firing.
- *Firing* is the discharge of the firearm by pulling the trigger, releasing the hammer or firing pin and striking the primer of the cartridge case.
- *Obturation* is a process sealing the bore and chamber due to pressure, forcing the projectile down the barrel.
- *Unlocking* is the opening of the bolt or breechblock.
- *Extraction* is the removal of the fired cartridge case from the chamber. Cartridge cases are designed with a rim or groove to facilitate extraction.
- *Ejection* is the process of removal of a fired cartridge case from the firearm. This is located on the opposite side of ejection port or opening for ease of the ejection.
- *Cocking* allows for semiautomatic firearms to repeat the cycle until the ammunition is exhausted.¹³⁷⁴

Machining processes contribute to class, sub-class and individual characteristics. Some class characteristics include parallel, concentric, arched, crosshatched, and smooth breechface marks. The firing pin by design also contributes to class characteristics, as manufacturers use different sized and shaped firing pins (hemispherical, rectangular/elliptical, flat-based, etc.). Another class characteristic is the firing pin aperture. The firing pin aperture is the opening through which the firing pin passes to contact the primer of the cartridge.

¹³⁷⁴ Monturo *Firearm Examination* 2019 [76].

Class characteristics can also be transferred onto the projectile as it passes through the barrel of the firearm. Every barrel consists of four class characteristics: caliber, direction of twist, number of lands and grooves, and width of the lands and grooves.¹³⁷⁵

With this multitude of interaction between the firearm and working pieces (projectiles and cartridge cases), the forensic examiner is requested to perform comparisons to identify all class, sub-class, and individual characteristics and form an opinion on source contribution. These comparisons are all based on subjective visualisation, starting with macroscopic visualisation and continuing to microscopic comparisons. In microscopic examination, examiners are challenged by the angle and intensity of the light shining on the impressed and striated marks on the working piece, as well as the reflection of the light due to the polished metal areas of the object. The appearance of the raised and lowered topography of the cartridge relies directly on the positioning of the light source on both objects being compared.

According to The Association of Firearm and Tool Mark Examiners (AFTE), examiners can come to a range of conclusions after completing their examinations:

- *Identification:* Agreement of all discernible class characteristics and sufficient agreement of a combination of individual characteristics where the extent of agreement exceeds that which can occur in the comparison of toolmarks made by different tools, and is consistent with the agreement demonstrated by toolmarks known to have been produced by the same tool.
- *Inconclusive:*
 - A. Agreement of all discernible class characteristics and some agreement of individual characteristics, but insufficient for an identification.
 - B. Agreement of all discernible class characteristics without agreement or disagreement of individual characteristics due to an absence, insufficiency, or lack of reproducibility.

¹³⁷⁵ Monturo *Firearm Examination* 2019 [88-89].

C. Agreement of all discernable class characteristics and disagreement of individual characteristics, but insufficient for an elimination.

- *Elimination*: Significant disagreement of discernable class characteristics and/or individual characteristics
- *Unsuitable*: Unsuitable for examination.¹³⁷⁶

8.4.1 Comparisons of cartridge cases

In the comparison of cartridges, the breechface is the primary focus for the examiner as it pertains to impressed and striated evidence of firing pin, primer flow back, aperture shear, firing pin drag, and an ejector mark. Secondary to the breechface marks, there will potentially be extractor marks, chamber marks, ejection port marks, magazine marks, slide drag marks, and bunter marks. The examiner will use a comparison microscope with an optical bridge consisting of a lens and prism system that combine the images of two different working pieces into a single eyepiece. The objects are aligned and enlightened in such a way that a side-by-side comparison of tool marks is possible. Examiners will initially compare class characteristics between the test-fired cartridge cases, before examining the evidence collected from the scene. Discrepancies on class characteristics between the markings of the unknown working piece from the crime scene, and the markings from a controlled working piece from the firearm in question should immediately be considered an “exclusion” of a firearm as source, and the comparison process between the two objects is terminated. If the class characteristics are in agreement, the comparison process can continue to sub-class and/or individual characteristic comparisons.¹³⁷⁷ During this process, examiners will first look at repeating marks between test fired cartridge cases from the same firearm. The examiner will then compare the test fires with the unknown cartridge to observe similar markings as the repeated marks between test-fires. In comparing all the markings between test-fires and evidence, the examiner will render an opinion on the findings. If the examiner identifies “enough” class characteristics, the results will indicate same source contributions to the firearm or a similar manufactured firearm. If individual characteristics are observed, the evidence will then be matched

¹³⁷⁶ AFTE “Range of Conclusions” <https://afte.org/about-us/what-is-afte/afte-range-of-conclusions> (Date of use: 25 November 2019).

¹³⁷⁷ Monturo *Firearm Examination* 2019 [163-194].

to the specific firearm. According to mechanical engineering terms, individual characteristics are approximately equivalent in scale to surface roughness irregularities.¹³⁷⁸ It is this subjective similarity metrics for pattern evidence comparison that is highly criticised.¹³⁷⁹ This point will be discussed later in this chapter.

8.4.2 Comparison of Projectiles

Projectile comparison is based on similar fundamental principles as cartridge cases and are also subjected to the machining process and removal of metal. Firearm barrels start as solid hardened metal bars, which are drilled through and reamed with the intended diameter for respective calibers. This process will leave individual characteristics. Additional characteristics are added during the rifling process where the metal inside the barrel is either removed (broach rifling), or disrupted and cut (button rifling). Comparison of projectiles are subjected to class characteristic comparison first and once agreement is reached on certain markings (direction of rifling twist, the number of lands and grooves, or width of lands and grooves) between the unknowns recovered on crime scenes, and knowns recovered in a crime laboratory as controls, individual characteristics will be examined. The barrel of a firearm has a wide range of individual characteristics that are carried over to projectiles, caused by drilling and rifling processes. They are attributed to tool wear, machine stability, and acceptable tolerances determined by the manufacturer. The quality and quantity of the individual characteristics on a projectile vary greatly depending on the condition of the barrel, projectile composition, and surface encountered by the projectile on impact (terminal point).¹³⁸⁰

During the past few years, several automated techniques for the comparison of marks has been proposed, mostly to support traditional subjective conclusions. Some have focused on finding matches, while others have focused on the resulting evidence strength associated with these

¹³⁷⁸ American National Standard ASME B46.1-2009: 2009 *Surface Roughness Waviness and Lay Am Soc Mech Eng New York.*

¹³⁷⁹ NAS *Report* [153–5].

¹³⁸⁰ Monturo C *Firearm Examination* 2019 [195-203].

matches.^{1381,1382,1383,1384} According to the FBI, it is imperative to know that the “human examiner cannot be completely disentangled from the science and viewed in isolation apart from the underlying physical properties of evidence specimens and therefore must be included in thorough going tests of the validity of the science”.¹³⁸⁵ In microscopic comparisons, the examiner is an observer who “draws a line” and forms opinions, because the similarities and dissimilarities between comparing objects lie along a nonlinear continuum and require a human observer to identify them.

8.4.3 *Number of test fires needed for comparison*

A problematic component within the larger science community, is where known source cartridge cases (test fires) of the firearm in question are compared to each other to evaluate repeating marks caused by the interaction of the firearm with the cartridge case. The question often asked is, how many test-fired cartridges should be compared to make statistical inferences on the variability within impressions left on cartridge cases by a firearm? A number of suggestions were made in the past, but none of them had a statistical reasoning.^{1386,1387,1388} In 2008, Heard¹³⁸⁹ proposed a minimum of four, but recommended more, as long as they are of similar make and type as the recovered cartridge cases found on the crime scene. Heard suggested that fired cartridge cases, under control, should be cross-compared to understand the similarities between them, and which markings can be disregarded, assuming that four test-fires were enough to represent the variability

¹³⁸¹ Monkres J *et al.* “Comparison and statistical analysis of land impressions from consecutively rifled barrels” 2013 *AFTE J* 45(1):3-20.

¹³⁸² Chu W *et al.* “Automatic identification of bullet signatures based on consecutive matching striae (CMS) criteria” 2013 *Forensic Sci Int* 231(1-3):137-141.

¹³⁸³ Riva F and Champod C “Automatic comparison and evaluation of impressions left by a firearm on fired cartridge cases” 2014 *J Forensic Sci* 59(3):637-647.

¹³⁸⁴ McLarin D “Adding an objective component to routine casework: use of Confocal Microscopy for the analysis of 9mm caliber bullets” 2015 *AFTE J* 47(3):161-170.

¹³⁸⁵ Bunch GS *et al.* “Is a match really a match? A primer on the procedures and validity of firearm and toolmark identification” 2009 *Forensic Sci Communication* 11(3).

¹³⁸⁶ Hatcher “Firearms investigation” 1957.

¹³⁸⁷ Heard “Firearms and Ballistics” 2008.

¹³⁸⁸ Warlow T *Firearms, the Law, and Forensic Ballistics* (3rd ed CRC Press 2012).

¹³⁸⁹ Heard “Firearms and Ballistics” 2008.

present within the firearm. Riva and Champod suggested in a paper how to obtain an objective assignment of the weight of cartridge case comparison evidence.¹³⁹⁰

They computed a likelihood ratio for each of the questioned cartridge cases, for an objective assignment of the weight of the evidence. Three different distributions were created, two within source and one between source distributions. However, the use of 60 test fires for in-source distribution was regarded as unrealistic for crime laboratory examiners on evidence submitted to the forensic laboratory. The researchers acknowledge that more research is required on the number of test fires in order to balance acquisition time with performance accuracy.

Many crime laboratories follow AFTE recommendations of a minimum of two test fires,¹³⁹¹ which holds no justifiable empirical value.¹³⁹² Two scholarly papers by Law *et al.*^{1393,1394} studied the number of test fires required to represent the variability present within firearms of various calibers, and statistically determined that 15 cartridge cases would be adequate to represent the match distribution for an unknown pistol or revolver, thus providing a good balance between Type I (false positive) and Type II (false negative) errors. However, the full match distribution was estimated for an unknown firearm of a given caliber, representing the variability present with the breechface and firing pin impressions. The distribution placement of the questioned cartridge case is not generally known and could be near the median of the distribution. It is, therefore possible that less than 15 test fires would be required, but additional studies are required to confirm the exact number needed. The aforementioned authors suggested two additional research topics that will assist in gaining a better understanding of the number of test-fires needed, namely to:

- Determine the most appropriate bounds for equivalence in both distribution location and dispersion, and

¹³⁹⁰ Riva "Automatic comparison" 2014.

¹³⁹¹ Alcohol, Tabaco and Firearms (ATF) "Examinations of Firearms" ATF-LS-FT1, <https://www.atf.gov/file/128841/download> (Date of use: 21 October 2019).

¹³⁹² Virginia Department of Forensic Science, Firearm/Toolmark Procedures Manual, (2019). Section 1.5.5 Test firing from the procedure manual "*In order to perform a microscopic comparison of a submitted firearm, a minimum of two (2) test shots should be fired and recovered.*"

¹³⁹³ Law EF *et al.* "Determining the number of test fires needed to represent the variability present within 9 mm Luger firearms" 2017 *Forensic Sci Int* 276:126-133.

¹³⁹⁴ Law EF *et al.* "Determining the number of test fires needed to represent the variability present within firearms of various calibers" 2018 *Forensic Sci Int* 290:56-61.

- Calculate likelihood ratios.

Generating a large number of images during comparisons and examinations requires computerised capturing and storage capabilities. Each examination cannot be kept in isolation and requires technology that will enable examiners to perform multiple comparisons with stored images.

8.5 Computerised imaging technology and databases

Similar to the other disciplines discussed in this thesis, a need for databases arose in the late 1980s, as examiners had to rely on the “cold searching” of an open file of test-fired cartridges to open case evidence. They also had to rely on memory, as a stockpile of cartridge cases were manually filed in categories, whilst searching the archive of cartridge casings was tedious and sometimes just disregarded. Information sharing between neighbouring jurisdictions was also impractical and impossible.

There was hence a need for computerised imaging and storage technology to assist forensic firearm examiners in finding links between unknown projectiles and cartridge cases found at crime scenes and suspected firearms that might have been used in crimes. In 1980, the first database, the “General Rifling Characteristic (GRC) file”, was shared by the FBI with the entire forensic community via the National Criminal Information Center (NCIC). This file provided information on 18,000 rifling characteristic measurements. Measurements provided were: number of lands and grooves; direction of twist; and measurement of land impressions. The majority of crime laboratories found the file to be very useful.¹³⁹⁵ With continuous developments, image capturing improved and led to two-dimensional (2D) automated comparison systems, and more recently during the past two decades, to three-dimensional (3D) systems.

¹³⁹⁵ National Forensic Science Technology Center, Florida International University, http://projects.nfstc.org/firearms/module10/fir_m10_t08_05.htm (Date of use: 2 November 2019).

8.5.1 Two-Dimensional Automated Comparison Systems

An automatic cartridge and projectile comparison system, based on two-dimensional surface screening ($z(x)$),¹³⁹⁶ was first seen in late 1989s. The FBI Law Enforcement, Laboratory Division announced the implementation of a new program — DRUGFIRE. The FBI's DRUGFIRE was a computer network database designed to digitally image fired projectiles and cartridge cases for comparisons within both the FBI laboratory and external forensic ballistic laboratories that also had remote access to the network.

However, offenders committing crimes in multiple jurisdictions faced a new development when a prototypical system, producing a digital map of the individualising detail on fired projectiles and cartridge cases, was developed in the early 1990s. This new technology developed by Forensic Technology Incorporated (FTI) of Montreal, Canada was labelled the Integrated Ballistic Identification System (IBIS), a combination of BULLETPROOF® (an automated projectile comparison system) and BRASSCATCHER™ (an automated cartridge case comparison system).¹³⁹⁷ IBIS allowed examiners to capture images and convert them into a format that mathematical algorithms could compare to other stored formatted images in the database. It allowed for a more objective search methodology than relying on human memory and subjective search methods. Soon after the IBIS inception within key law enforcement agencies, performance

¹³⁹⁶ A Cartesian coordinate system in two dimensions (also called a rectangular coordinate system or an orthogonal coordinate system) is defined by an ordered pair of perpendicular lines (axes), a single unit of length for both axes, and an orientation for each axis. The point where the axes meet is taken as the origin for both, thus turning each axis into a number line. For any point P, a line is drawn through P perpendicular to each axis, and the position where it meets the axis is interpreted as a number. The two numbers, in that chosen order, are the Cartesian coordinates of P. The reverse construction allows one to determine the point P given its coordinates.
https://www.encyclopediaofmath.org/index.php/Cartesian_orthogonal_coordinate_system (Date of use: 25 January 2020).

¹³⁹⁷ Thompson RM "Automated firearms evidence comparison using the Integrated Ballistic Identification System (IBIS)" ATF San Francisco Laboratory Center.

and validation studies showed exceptional results.^{1398, 1399, 1400} The studies highlighted a number of advantages using IBIS:

- It maximised firearm examiner skills by allowing examiners to spend more time on microscopic examinations than searching for comparative stored objects.
- It reduced the subjectivity of human searching and relying on human memory.
- It provided fast investigative leads that would help links in drug/gun trafficking or even terrorist activities.
- It allowed for intelligence sharing and networking between jurisdictions or between countries.

The FBI and the Bureau of Alcohol, Tobacco, Firearms and Explosives (ATF) used two different systems. The two agencies realised the two systems were incompatible and needed some form of integration. In 1996, the National Institute of Standards and Technology (NIST), Gaithersburg, Maryland, was directed to provide technical assistance to assist with “ballistic imaging interoperability” between the DRUGFIRE database of the FBI and the CEASEFIRE database of the ATF.

In May 1997, the National Integrated Ballistics Information Network (NIBIN) Board was created to develop a national imaging system. At the end of 1999, a memorandum defining the roles of both the FBI and ATF, was signed, granting the ATF the responsibility to run and maintain the NIBIN. The system was rolled out to various local and state crime laboratories, representing more than 174 agencies.¹⁴⁰¹ The first interchanging of data made it possible for the ATF “to evaluate the

¹³⁹⁸ Kunz P and Terry D “Benchmark Evaluation Studies of the Bulletproof and Drugfire Ballistics Imaging Systems” October 1994 *HARC Report Number FTR92394*. Prepared for the Office of National Drug Control Policy/Counterdrug Technology Assessment.

¹³⁹⁹ Thompson RM et al. “Computerized Image Analysis for Firearms Identification; The Integrated Ballistic Identification System (IBIS) BRASSCATCHER Performance Study” 1996 *AFTE J* 28(3):194-203.

¹⁴⁰⁰ Tontarski RE “Automated Ballistic Comparison: Forensic Tool for Firearms Identification” 25-28 October 1994 *DFS-94 7th Joint Service Data Fusion Symposium* 71-82.

¹⁴⁰¹ Thompson RM “Firearm Identification in the Forensic Science Laboratory” Bureau of Justice Assistance under grant number 2008-MU-MU-K004 awarded to the National District Attorneys Association, 2010.

impact of operator variability on image quality and matching, networking limitations, and ease of operator use for data entry, as well as correlations and system maintenance.”¹⁴⁰²

The rapid development of ballistic imaging technology led to some speculation about its future potential and a proposal was made to create a national reference ballistic image database (RBID) that would capture images of fired references of all newly manufactured or imported firearms.¹⁴⁰³ Some states in the United States already had RBID databases since 2000. Maryland and New York collected images for all new handguns sold in those states, but were barred from direct networking their RBID data with crime scene based NIBIN data.¹⁴⁰⁴ The California Department of Justice was tasked to study the feasibility of such a system in the state, but found it to be not feasible and suggested further studies be conducted on a national level.

After the sniper shootings during October 2002 in Washington D.C., more states¹⁴⁰⁵ proposed the creation of RBID databases. An RBID database was also under discussion outside the United States, with Belgium and other member states of the European community exploring national level systems.¹⁴⁰⁶ The U.S. Congress saw a number of bills introduced to create a national RBID, but none of them advanced to appropriate committees.¹⁴⁰⁷ Some view such laws as essential in

¹⁴⁰² Thompson RM (1998b, November) “Automated firearms evidence comparison using the Integrated Ballistic Identification System (IBIS)” In: *Part of the SPIE Conference on Investigation and Forensic Technologies*. (Boston, MA: International Society for Optical Engineering 1998) [94–103].

¹⁴⁰³ De Kinder *et al.* “Reference ballistic imaging database performance” 2004 *Forensic Sci Int* 140:207-215. Also, De Ceuster and Dujarden S “The reference ballistic imaging database revisited” 2015 *Forensic Sci Int* 248:82-87.

¹⁴⁰⁴ National Research Council 2008 “*Ballistic Imaging*” Washington, DC: The National Academies Press. <https://doi.org/10.17226/12162>, [12]. (Date of use: 4 November 2019)

¹⁴⁰⁵ Butterfield F “The hunt for a sniper: Technology—Now, 4 states look to start tracing shells and bullets” 2002-10-24 *New York Times*. Available: <http://query.nytimes.com/gst/fullpage.html?res=9D06E6D8123CF937A15753C1A9649C8B63> (Date of use: 4 November 2019).

¹⁴⁰⁶ De Kinder J “Review—AB 1717 report, technical evaluation: Feasibility of a ballistics imaging database for all new handgun sales” 2002b *December Independent review for California Department of Justice National Institute for Forensic Science Belgium*.

¹⁴⁰⁷ 108th Congress, the Technological Resource to Assist Criminal Enforcement (TRACE) Act (S. 469/H.R. 776) and the So No Innocent Person Ever Repeats (SNIPER) the Sniper Tragedy Act of 2003 (S. 1983), the latter of which incorporated the former in its entirety, as well as the Bullet Tracing Act to Reduce Gun Violence Act (H.R. 24). In the 107th Congress, see the Ballistics, Law Assistance, and Safety Technology (BLAST) Act (H.R. 5663) and the Bullet Tracing Act to Reduce Gun Violence Act (H.R. 422). Earlier versions of the Bullet Tracing and BLAST Acts were also introduced in the 106th Congress.

reducing gun violence, but others regard these as a violation of the Second Amendment's right to bear arms. In both the 107th and 108th Congresses, bills were introduced to require that the National Academies conduct a study of the state of ballistic imaging technology.¹⁴⁰⁸

In 2004, the National Institute of Justice (NIJ) of the U.S. Department of Justice requested that the National Academies appoint a committee of experts to address the issues raised by the computerised imaging ballistics technology. The committee was tasked to assess three main aspects related to feasibility, accuracy, and reliability of National Databases. More precisely, the committee was required to:

- Assess the technical feasibility, through analysis of the uniqueness of ballistic images; the ability of imaging systems to capture unique characteristics and to parameterise them; the algorithmic and computational challenges of an imaging database; the reproducibility of ballistic impressions and the ability of imaging systems to extract reproducible information from ballistic impressions.
- Assess the statistical probabilities that ballistics evidence presented would lead to a match with images captured in a database; whether and how the base rate can be estimated for those crimes that present bullet or casing evidence that do in fact come from a gun that produced a database entry; and the probabilities and consequences of false positives and false negatives.
- Assess the operational utility of ballistics evidence in criminal investigations that is the extent to which it is used or can be used to identify crime guns and suspects and to solve specific crimes.
- Assess the sources of error in ballistics database matching (from examination, digitisation, computer matching, chain of custody and documentation of tests, and expert confirmation); how they may be quantified, and how these errors interact.¹⁴⁰⁹

¹⁴⁰⁸ 108th Congress, H.R. 3491 and S. 2581 in the 107th Congress and H.R. 2436 and S. 980. These bills also failed to advance beyond referral to subcommittees.

¹⁴⁰⁹ National Research Council (US) "Committee to Assess the Feasibility, Accuracy, and Technical Capability of a National Ballistics Database" Also, Cork DL *et al.* *Ballistic Imaging* (The National Academies Press 2008).

In spite of successes from 2007 to 2010, when approximately 1,400,000 pieces of firearm evidence had been entered in the database and resulted in over 23,000 “cold hits”,¹⁴¹⁰ not all of the NRC committee findings were in favour of the technological advances.

Although the systems were able to deal with high sample throughput, it still heavily relied on human factors for their efficient performance. The quality of results was determined by the data operator’s procedure and thoroughness capturing the data. A number of variables influenced the quality of the capturing data, such as not keeping the surfaces parallel; wrong degree of lighting; incorrect orientations of the breechface; incorrect area of interest, and object surface out of focus. A number of research papers subsequently appeared in forensic science and other journals to improve data capturing and correct IBIS installations internationally.^{1411,1412,1413,1414,1415,1416}

The NRC committee acknowledged the usefulness of the technology for automated toolmark comparison, based on greyscale images, for gross categorisation and sorting of large quantities of samples, but rejected the usefulness for distinguishing extremely fine individual marks for successful matching.¹⁴¹⁷ The committee also felt that the probability calculations depended on critical measures of similarity between and within firearm types that have not been derived yet. The committee also stressed their concern of a single vendor source solving the problems associated with the technology and suggested a better all-inclusive vendor procurement process.¹⁴¹⁸ Prior to

¹⁴¹⁰ “A cold hit is defined as an association made by only using NIBIN without any other leads within an investigation. For example, a firearm was recover or seized at a different time and place than the crime scene and at first not associated with any crime at the time of recovery or seizure.”

¹⁴¹¹ Argaman U *et al.* “Utilisation of the IBIS in Israel” 2001 *AFTE J* 33(3):269-272.

¹⁴¹² Zanz FJ (Nacional de Policia Spain) “IBIS in the Spanish Police 2000-2004” 2004 *International forensic technology symposium, Rome Italy* 4-5.

¹⁴¹³ Aguilar MO “Integrating IBIS into the PGR laboratory workflow” 2004 *International forensic technology symposium Rome Italy* 4-5.

¹⁴¹⁴ Geradts ZJ *et al.* “Image Matching Algorithms for Breechface Marks and Firing Pins in a Database of Spent Cartridge Cases of Firearms” 2001 *Forensic Sci Int* 119(1):97-106.

¹⁴¹⁵ Giverts P *et al.* “An average phase scoring for bullets, in the IBIS correlation results” 2002 *AFTE J* 34(2):199-202.

¹⁴¹⁶ Rector M “Effects of ultrasonic cleaning of bullets on IBIS correlation scores: A preliminary report” 2002 *AFTE J* 34(2):165-168.

¹⁴¹⁷ NRC Report 2008 [5].

¹⁴¹⁸ NRC Report 2008 [8-9].

and during the course of this study, new three-dimensional (3D) technology was introduced to the forensic firearm community.

8.5.2 *Three Dimensional Automated Comparison System*

The three-dimensional systems ($z(x,y)$)¹⁴¹⁹ were first introduced in the early 2000s and early literature showed more stability and less sensitivity to “noise” than the two-dimensional systems. In 2005, Forensic Technology Incorporated (FTI) announced the deployment of their BULLETRAX-3D™ projectile imaging system. In 2006, they introduced their BRASSTRAX-3D™ cartridge case imaging system. Both BULLETRAX-3D™ and BRASSTRAX-3D™ (IBIS-TRAX 3D™) use confocal microscopy to create a 3D image of the fired projectiles and cartridge casings for analysis.¹⁴²⁰ The goal of the company is to replace the current IBIS heritage, which only records the acquired data in 2D. The new systems are able to integrate with the existing IBIS systems until the traditional systems are replaced. Early papers of Bachrach¹⁴²¹ and Banno¹⁴²² indicate positive results using these 3D systems. Brinck¹⁴²³ made a direct comparison on the performance of IBIS and BULLETRAX-3D technology, by searching projectiles (both jacketed and lead) discharged from 10 consecutively rifled barrels. He assessed the systems on both the correctness of finding a hit, and where in the correlation list that hit occurred. Another aspect assessed was the quality of the images captured by both systems. Brinck determined that the BULLETRAX-3D was slightly better for jacketed projectiles, but for lead projectiles, the IBIS could only correlate 30 per cent of

¹⁴¹⁹ A Cartesian coordinate system for a three-dimensional space consists of an ordered triplet of lines (the axes) that go through a common point (the origin), and are pair-wise perpendicular; an orientation for each axis; and a single unit of length for all three axes. As in the two-dimensional case, each axis becomes a number line. For any point P of space, one considers a hyperplane through P perpendicular to each coordinate axis, and interprets the point where that hyperplane cuts the axis as a number. The Cartesian coordinates of P are those three numbers, in the chosen order. The reverse construction determines the point P given its three coordinates.

¹⁴²⁰ Roper-Miller J “Forensic Optical Topography: A Landscape Study” Forensic Technology Center of Excellence NIJ Award Number 2011-DN-BX-K564, 2016.

¹⁴²¹ Bachrach B “Development of a 3D-Based automated firearms evidence comparison system” 2002 *J Forensic Sci* 47(6):1253-1264.

¹⁴²² Banno A “Possibility of bullet identification using 3D data” 2003 *Japanese-J Sci Tech Ident* 8(1):81-97.

¹⁴²³ Brinck TB “Comparing the performance of IBIS and BulletTRAX-3D Technology using bullets fired through 10 consecutively rifled barrels” 2008 *J Forensic Sci* 53 (3):677-682.

the hits in the first 20 positions, whereas the 3D system correlated a 100 per cent. Image quality was also better for the 3D system.

De Smet *et al.*¹⁴²⁴ performed a variability study between traditional optical and 3D measuring techniques, looking at the initial seating depth of the primer and the marks found on the breechface. They determined that no clear impact on the primer striation patterns could be found, but noted variances in the firing pin impressions. No additional information for arriving at these conclusions were added, using the 3D measuring technology.

Sakarya *et al.*¹⁴²⁵ studied automated segmentation of markings present on the base of discharged cartridge casings, a preliminary step for the matching process. They distinguished the firing pin impression and headstamp based on 3D images. Heikkinen *et al.*¹⁴²⁶ utilised the IBIS® BULLETRAX-3D™ to study the usefulness of the technique in determining the order of placement of a variety of toolmarks. They determined that the 3D technique provided more detail than the 2D technique in addressing the order of creation and the examination of directional engraved marks.

The Forensic Technology Incorporated (FTI)¹⁴²⁷ currently has ballistics-imaging equipment (2D and 3D) in more than 39 countries globally. Inter-comparison of fired components has been reported between states in the United States, as well as between countries in Europe. These systems are powerful and deal with the growing number of crime scene samples submitted for comparison and decreased turnaround times and backlogs.

¹⁴²⁴ De Smet P *et al.* "Experimental evaluation of the impact of seating depth variations on observed marks on primers" 2008 *Forensic Sci Int* 179(2-3):163-171.

¹⁴²⁵ Sakarya U *et al.* "Automated region segmentation on cartridge case base" 2012 *Forensic Sci Int* 222:277-287.

¹⁴²⁶ Heikkinen V *et al.* "Quantitative high-resolution 3D Microscopy improves confidence when determining the order of creation of toolmarks" 2013 *AFTE J* 45(2):150-159.

¹⁴²⁷ Forensic Technology pioneered automated ballistics identification more than a decade ago and continues to be a leader in ballistics and firearms identification technologies that promote a safer society. We partner with hundreds of public safety agencies in over 39 countries and territories, providing cost-effective and sustainable solutions. With vast experience in scalable-networked solutions, we employ a dedicated team of engineering, forensic, and law enforcement professionals around the world. <https://www.officer.com/training-careers/specialized-training/company/10029098/forensic-technology-inc> (Date of use: 20 January 2020).

In 2013, the NIST proposed a NIST Ballistics Identification System (NBIS) for fast evidence searching and accurate ballistics identifications, using 3D topography measurements. The marks for comparison are subdivided into correlation cells, which would objectively identify “valid” or “invalid” correlation areas.¹⁴²⁸ Researchers at NIST used the NBIS to study the breechfaces of 40 cartridge cases discharged from 10 consecutively manufactured slides, and discovered significant separation between the known match and known non-match distributions of the counts of the congruent matching cells (CMC). They found no false positive or false negative identifications, which verified their proposed NBIS numerical identification criterion.¹⁴²⁹

The problem of determining the order of creation of toolmarks on discharged cartridge cases and projectiles was the focus of a study by Heikkinen *et al.*,¹⁴³⁰ when they employed quantitative high resolution large area 3D optical imaging for traceable comparison. Previous studies were only conducted on qualitative 2D imaging. With the added 3rd dimension, a higher level of confidence was detected by examiners.

In 2015, McClarin published a paper¹⁴³¹ on employing the confocal microscope into casework samples as an objective technique that will complement traditional examination methodology. A large number of laboratories still use 2D technology and did not make the transition to 3D technology for various reasons. This will be discussed later in this chapter in the section on future developments in this field.

All these developments did not take place in isolation, but were shared within a larger community of firearm examination entities. With the growth of the discipline and the technology associated with it, the need for standardisation was addressed early in the 20th century.

¹⁴²⁸ Song J “Proposed ‘NIST Ballistics Identification System (NBIS)’ based on 3D Topography measurements on correlation cells” 2013 *AFTE J* 45(2):184-194.

¹⁴²⁹ Chu W *et al.* “Validation tests for the congruent matching cells (CMC) method using cartridge cases fired with consecutively manufactured pistol slides” 2013 *AFTE J* 45(4):361-366.

¹⁴³⁰ Heikkinen Quantitative high-resolution 3D 2013.

¹⁴³¹ McClarin D “Adding an objective component to routine casework: Use of Confocal Microscopy for the analysis of 9mm caliber bullets” 2015 *AFTE J* 47(3):161-170.

8.6 Standardisation

In order to get a better understanding of how standardisation in this field developed, it is necessary to provide a brief account of the historical events that would provide a foundation underpinning the discipline and the development of standards followed within the discipline.

In New York City, New York (USA), the Bureau of Forensic Ballistics was established by C. E. Waite, Calvin H. Goddard, Philip O. Gravelle and John H. Fisher in April 1925.¹⁴³² The purpose of the Bureau was to provide a firearm identification service throughout the United States.

In June 1925, the Saturday Evening Post published a two-part series of articles, titled “Fingerprinting Bullets”.¹⁴³³ In the first article, W.S Stout commented as follows on firearm identification:

“Today, it may be set down as a scientific fact, and a postwar discovery now first made public, that no two revolvers or pistols ever leave precisely the same marks upon a bullet, and that it now is possible and practicable to link the bullet to the weapon in virtually every instance.”

The articles also disclosed details of activities within the Bureau of Forensic Ballistics, and the science involved in firearms identification examinations. The wide circulation of the articles informed the public about the science behind firearm identification and the services the Bureau rendered.¹⁴³⁴

The ability to establish that a bullet had been fired from a particular weapon was proclaimed the new science of forensic ballistics and was validated by testimonials.¹⁴³⁵ The use of the comparison

¹⁴³² Warlow “Firearms, the Law, and Forensic Ballistics” 2012.

¹⁴³³ Drogin EY “Science and Lawyers” 2007 American Bar Association Section of Science and Technology.

¹⁴³⁴ American Bar Association
https://apps.americanbar.org/abastore/products/books/abstracts/5450051chap1_abs.pdf (Date of use: 2 November 2019).

¹⁴³⁵ Goddard CH “Firearm as Evidence” 1931 *The Am J of Police Sci* 2:3. Also, Goddard, CH :A History of Firearm Identification” 1985 *AFTE J* 17(1):55 – 68 (originally printed in Chicago Police Journal 1936). On April 18, 1925, he was in the position to demonstrate his discovery and begin to solicit

microscope was hailed as having eliminated opinion evidence and provided unimpeachable evidence by means of almost positive accuracy approaching infallibility.¹⁴³⁶ According to the Chicago Daily Times in 1929, this “science”, which was to be such an aid to firearms identification, was also predicted to become a major deterrent against the use of firearms in the commission of a crime.¹⁴³⁷

In 1948, a meeting convened as part of the “First American Medico-legal Congress” was held in St. Louis, Missouri. It led to a second meeting later the same year and follow-up sub-committee meetings in 1949. It was the start of bringing scientists and examiners together, which later changed its name to “American Academy of Forensic Sciences” in 1950. Two of the papers presented at the first meeting were related to firearms identification. Over time, firearms examiner practitioners met informally on regular intervals to discuss their cases, and they later established the Association of Firearm and Toolmark Examiners (AFTE) in 1969, 19 years after the initial AAFS meeting in 1950.¹⁴³⁸

In 1980, the AFTE published the AFTE Glossary. The glossary consisted of 219 pages of definitions and illustrations related to the field of firearm and toolmark identification, commonly used abbreviations, various formulas for determining bullet energy and rate of spin, and useful chemical formulas.¹⁴³⁹ The glossary consisted of information gathered from the five-member AFTE Standardisation Committee, assisted by at least 57 other forensic practitioners. A second, comprehensive edition was published in 1982, followed by a third edition of the glossary in 1994. The third edition featured material from the first two editions with additional definitions and illustrations; new appendices which included definitions for computer terminology, fingernail examination (a toolmark in a biological matrix), knives, machining terms, gunshot wound terminology, and shooting scene reconstruction terminology.

testimonials. Endorsements were subsequently obtained from Joseph Faurot, Deputy Police Commissioner of New York, Salvatore Ottolenghi, Director of Scientific Police School, Rome and Judge Otto A. Rosalsky of the New York City Court.

¹⁴³⁶ Goddard *Scientific Investigation* [256, 260, 263].

¹⁴³⁷ Herman N et al. “Forensic Ballistics” *Chicago Daily news* (1929) 1.

¹⁴³⁸ AFTE <https://afte.org/about-us/history> (Date of use: 3 October 2019).

¹⁴³⁹ AFTE Glossary 1st, 2nd and 3rd editions 1994. <https://afte.org/news/afte-glossary-update> (Date of use: 3 October 2019).

AFTE published an official training manual, in 1982, as modular guides for the training of firearm and toolmark examiners. The AFTE Training Committee intended to develop and provide a modular education program that could then be tailored to meet the needs of forensic firearm examiners and the laboratories they worked in. The training manual consisted of more than 400 pages that provided an excellent source of material for assisting in training multiple firearm and toolmark examiners, and was compiled by the works of six experienced firearm examiners.

In 1986, the FBI's Forensic Science Research & Training Center (FSRTC), at Quantico, VA (the FSRTC is part of the FBI Laboratory Division) started presenting a training module for new firearms and toolmark examiners. The module called, "Specialized Techniques in Firearms Identification", was designed for court-qualified examiners and consisted of a range of topics designed to enhance proficiency levels of practitioners.

The AFTE hosted its 20th Anniversary Annual Training Seminar in Virginia Beach, VA in 1989, attended by 210 individuals, representing 12 countries. Subsequent to the seminar, numerous articles based on research concerning both criteria for identification studies and striae reproducibility on firearms barrels followed, appearing also in the AFTE Journal (volume 30, number 1). These research articles and several others were dedicated to the Daubert challenge, and the continuous process by members of AFTE to articulate the science behind the discipline of firearm and toolmark identification.

In 1998, the Federal Bureau of Investigation (FBI) established the Scientific Working Group for Firearms and Toolmarks (SWGUN). The purpose of SWGGUN was to develop a series of agreed guidelines for the firearm and toolmark discipline and to circulate these guidelines, studies, and other findings that may be beneficial to the forensic community. The SWGGUN consisted of 21 experienced and knowledgeable individuals within the discipline of firearms and toolmarks.

In January of the same year, the AFTE and Cooperative Personnel Services (CPS) develop a series of content-valid certification examinations in three different competency areas. Each

certification examination developed under this contract consisted of a written examination and a practical examination. Certification examinations were developed to offer the following tests for certification:

- Firearm Evidence Examination and Identification;
- Toolmark Evidence Examination and Identification; and
- Gunshot Residue Evidence Examination and Identification.

All successful certified examiners have their names published on the AFTE website.¹⁴⁴⁰

In 1990, some members of the AFTE participated as members of the Angoff Committee, who provided guidelines of the assessment methodology to be utilized as part of a continuous certification study program. The ultimate goal of the Association was to offer a certification program to qualified AFTE members. The purpose in presenting the program was two-fold:

- To act toward the public benefit by attesting that successful applicants meet certain standards as defined by members of AFTE, and
- To promote professionalism among firearm and toolmark examiners by establishing certification as a level of accomplishment.¹⁴⁴¹

At its 30th Anniversary celebration, in 1999, the AFTE conducted the Annual Training Seminar, which was held in Williamsburg, Virginia. The membership of AFTE numbers was approximately 850 members, technical advisors and subscribers that represent over 40 countries from around the world.

Also in 1999, the Bureau of Alcohol, Tobacco and Firearms (ATF) announced the formation of the “ATF National Firearm Examiner Academy” (NFEA) for the purpose of providing training for

¹⁴⁴⁰ AFTE <https://afte.org/afte-certification/certified-member-roster> (Currently there are 148 certified examiners on the list. The geographical data of certified examiners are not disclosed on the dataset). (Date of use: 10 October 2019).

¹⁴⁴¹ AFTE <https://afte.org/store/product/toolmark-identification-practical-test> (Date of use: 24 January 2020).

apprentice/entry level firearm and tool-mark practitioners from Federal, State and local law enforcement agencies. The NFEA was developed in conjunction with AFTE.

The Admissibility Resource Kit (ARK) was developed and published on AFTE's website in 2005 by the SWGGUN Daubert Committee, tasked with devising a training program/tool that could assist firearm examiners to better prepare for evidence admissibility hearings, which began to greatly proliferate in 2002. The ARK was divided into the following categories:

- Admissibility Rules Overview
- Foundational Overview of Firearm/Toolmark Identification
- Review of Admissibility Elements
- Court Rulings
- Opposing and Supportive Viewpoints of Firearm and Toolmark Identification
- Appendices

Each topic highlighted a number of significant legal cases and decisions made where the law challenged firearm science. Those cases, as well as other cases relevant to the field of firearm and toolmark evidence, will be discussed later in this chapter as it important to first understand the statistical foundations underpinning the discipline.

8.7 Statistical foundations

Historically, the hypothetical formalised scientific method was based on a conception of “when rendering an opinion, we conclude that the tool responsible for making the mark is individualized to the exclusion of all other tools”.¹⁴⁴² Theoretically, this is impossible unless all tools in the world have been initially examined by the examiner. The impossibility was recognised by Gunther¹⁴⁴³

¹⁴⁴² Grzybowski R et al. “Passing the reliability test under Federal and State evidentiary standards” <https://afte.org/uploads/documents/swggun-fatm-id-reliability.pdf> (Date of use: 24 January 2020).

¹⁴⁴³ Gunther CO “Markings on bullets and shells fired from small arms” 1932 *Mechanical Engineering* 54:341-345.

and Hatcher¹⁴⁴⁴ as early as the 1930s. Nichols^{1445,1446} summarised scientific studies which may assist examiners to predict individualisation without having to compare all tools that exist in the world, but assumed no subclass influence. According to the FBI,¹⁴⁴⁷ two propositions constitute the scientific foundation for firearm and toolmark examinations. The propositions were defined by the Scientific Working Group for firearm and toolmarks (SWGUN) in 2007 as follows:

- Toolmarks imparted to objects by different tools will rarely if ever display agreement sufficient to lead a qualified examiner to conclude the objects were marked by the same tool. That is, a qualified examiner will rarely if ever commit a false positive error (misidentification).
- Most manufacturing processes involve the transfer of rapidly changing or random marks onto work pieces such as barrel bores, breechfaces, firing pins, screwdriver blades, and the working surfaces of other common tools. This is caused principally by the phenomena of tool wear and chip formation, or by electrical/chemical erosion. Microscopic marks on tools may then continue to change from further wear, corrosion, or abuse.¹⁴⁴⁸

It enables firearm examiners to distinguish between two classes of items, namely those marked by the same source and those marked by different sources. The second proposition is based on whether trained humans or machines can reliably distinguish between toolmarks made by one source versus toolmarks made by other sources. For the first proposition, validation studies and statistical foundations within the field of firearm and toolmark examination were traditionally based on reproducibility of markings, and individuality of markings.

The next two paragraphs in this thesis, 8.7.1 and 8.7.2, will provide an overview of research efforts conducted by prominent researchers and practitioners with an invested interest in the field. The

¹⁴⁴⁴ Hatcher JS *Textbook of firearms investigation, identification and evidence* (Marines NC: Small Arms Technical Publishing Company 1935).

¹⁴⁴⁵ Nichols R "Firearm and toolmark identification criteria: A review of the literature" 1997 *J Forensic Sci* 42(3):466-474.

¹⁴⁴⁶ Nichols R "Firearm and toolmark identification criteria: A review of the literature, Part II" 2003 *J Forensic Sci* 48(2):318-327.

¹⁴⁴⁷ Bunch "Is a Match Really a Match" 2009.

¹⁴⁴⁸ AFTE <https://afte.org/uploads/documents/swgun-bunch.pdf> (Date of use: 24 January 2020).

majority of these research papers were selected, based on the SWGGUN and AFTE's response to answer 25 key questions from the NAS in a quest to validate the methodology followed within firearms and toolmark examinations.¹⁴⁴⁹

8.7.1 *Reproducibility of markings*

Validation studies on reproducibility would normally follow the path of discharging large amounts of ammunition by using a single source (firearm) and compare the markings for consistent marking transfers. Over time, many studies in this regard were performed on various firearms.

One of the first studies in this regard was reported by Kirby,¹⁴⁵⁰ who discharged 900 lead bullets from a .455 caliber revolver. He was able to correctly connect all of the cartridge cases recovered from that revolver back to that source. In 1972, Hamby¹⁴⁵¹ collected 501 .223 caliber full metal jacket projectiles discharged rapidly from an M16A1 assault rifle, and compared every 100th projectile for similarities. Using an optical comparison microscope, he was able to identify enough similarities that connected them to one firearm source. His results were confirmed by a second qualified firearm examiner.

A more extensive research study was conducted by Ogihara *et al.*,¹⁴⁵² when 5 000 projectiles and cartridge cases were collected after being discharged by a M1911A1 .45 ACP caliber semiautomatic pistol. Every 10th discharged projectile and cartridge were collected and distributed between various examiners in forensic science laboratories in Japan. Results were compared and

¹⁴⁴⁹ SWGGUN and AFTE Committee for the Advancement of the Science of Firearm and Toolmark Identification's response to 25 foundational firearm and toolmark examination questions received from the Subcommittee on Forensic Science (SoFS), Research, Development, Testing, & Evaluation Interagency Working Group (RDT&E IWG) on April 18, 2011. This response is a compilation of published research which addresses each question. Published June 14, 2011. <https://www.nist.gov/system/files/documents/forensics/Annotated-Bibliography-Firearms-Toolmarks.pdf> (Date of use: 24 January 2020).

¹⁴⁵⁰ Kirby S "Comparison of 900 consecutively fired bullets and cartridge cases from a .455 Caliber S & W Revolver" 1983 *AFTE J* 15(3):113-125.

¹⁴⁵¹ Hamby J "Identification of Projectiles" 1974 *AFTE J* 6(5-6):22.

¹⁴⁵² Ogihara Y *et al.* "Comparison of 5000 consecutively fired bullets and cartridge cases from a 45 Caliber M1911A1 Pistol" 1983 *AFTE J* 15(3):127-140.

they determined that all 5 000 projectiles and cartridge cases had been discharged from the same firearm.

Shem and Striupaitis¹⁴⁵³ conducted a study comparing the cartridge casings of 501 consecutively fired rounds from a .25 caliber Raven semiautomatic pistol. They collected every 10th projectile and cartridge case for examination, and concluded that even though changes occurred in the projectiles and breechface striae, enough similarities were observed to connect them to one source.

Schechter *et al.*¹⁴⁵⁴ discharged 7 100 rounds using a variety of .223 caliber ammunition with a new GALIL rifle. They focused on the ejector marks only and determined from the 9th to the 7 060th fired cartridge case ejector marks were consistent to the firearm. In another study, Vinci *et al.*¹⁴⁵⁵ discharged 2 500 rounds of ammunition from a .45 ACP caliber Springfield Armory semi-automatic pistol and examined every 100th fired cartridge case. They observed both class and individual characteristics and determined that it was possible to identify all 2 500 cartridge casings been fired by the pistol.

Uchiyama¹⁴⁵⁶ assessed the reproducibility of the markings by discharging 100 rounds of ammunition and using a homemade image retrieval and identification system. He discovered noticeable differences in the shape of the land impressions for different brands of ammunition. This variability may cause forensic examiners to eliminate projectiles early during comparison, especially when lacking knowledge of the variabilities between brands. Uchiyama also observed a shift in markings between shots and attributed this to the differences in projectile velocity and/or diameter. Lastly, he discovered that for cartridges from different brands, the size of the primer area of contact with the breechface and firing pin were different, but consistent between similar

¹⁴⁵³ Shem R and Striupaitis P "Comparison of 501 consecutively fired bullets and cartridge cases from a .25 caliber raven pistol" 1983 *AFTE J* 15:109–112.

¹⁴⁵⁴ Schechter B *et al.* "Extended firing of a GALIL assault rifle" 1992 *AFTE J* 24(1):37-46.

¹⁴⁵⁵ Vinci F *et al.* "Morphological Study of Class Characteristics Produced by Firing 2500 Cartridges in a .45 Caliber Semi-Automatic Pistol" 2005 *AFTE J* 37(4):368-372.

¹⁴⁵⁶ Uchiyama T "Toolmark reproducibility on fired bullets and expended cartridge cases" 2008 *AFTE J* 40 (1):3-46.

manufactured ammunition. A later study, Davis¹⁴⁵⁷ confirmed the differences in markings from primer cup properties between various manufacturers. He used seven different types of 9mm Luger cartridges and four different firearms, with four different breechface manufacturer marks. The transferred markings from both nickel plated and brass primer cups of similar hardness corresponded.

Gouwe *et al.*¹⁴⁵⁸ increased the number of rounds fired by a single source to 10 000 rounds, when they discharged the ammunition from a Glock .40 caliber pistol. They were able to identify all 10 000 cartridge casings to each other by using both traditional matching and the congruent matching cells (CMC) technique. They mentioned that, at the time, the CMC technique had the potential to provide the examiner with additional resources. Mikko *et al.*¹⁴⁵⁹ discharged 20 000 rounds of ammunition through a M240 machine gun. The researchers noticed some prominent striae on the projectiles that changed significantly after 10 300 rounds were discharged.

Grom and Demuth¹⁴⁶⁰ studied the breechface and firing pin markings after discharging 500 rounds of ammunition through a Glock pistol. The IBIS system was able to correlate the known matches within the top 20 % of the results entered into the system. They discovered no significant changes of the markings on the cartridges and determined the markings to be reproducible.

Stowe¹⁴⁶¹ tested the persistence of chamber marks from two semi-automatic pistols when he discharged 1 440 rounds of ammunition. No significant changes were noticed, but finer markings masked some detail in some cartridge cases from around the 100th round. A total of 67 % of the discharged ammunition were identifiable. The one prominent reason for the lack of striae on some cartridge cases was the manufacturing material used.

¹⁴⁵⁷ Davis JJ "Primer cup properties and how they affect identification" 2010 *AFTE J* 42 (1):3-22.

¹⁴⁵⁸ Gouwe J *et al.* "Comparison of 10,000 Consecutively Fired Cartridge Cases from a Model 22 Glock .40 S&W Caliber Semiautomatic Pistol" 2008 *AFTE J* 40 (1):57-63.

¹⁴⁵⁹ Mikko D *et al.* "Reproducibility of toolmarks on 20,000 bullets fired through an M240 machine gun barrel" 2012 *AFTE J* 44 (3): 248-253.

¹⁴⁶⁰ Grom TL and Demuth WE "IBIS correlation results of cartridge cases collected over the course of 500 firings from a Glock pistol" 2012 *AFTE J* 44 (4):361-363.

¹⁴⁶¹ Stowe A "The persistence of chamber marks from two semiautomatic pistols on over 1,440 sequentially-fired cartridge cases" 2012 *AFTE J* 44 (4):293-308.

Experienced examiners should avoid matching GLOCK semi-automatic 9mm pistols to fired cartridge cases by only focusing on the firing pin aperture. This was the finding by Hamby *et al.*,¹⁴⁶² who used an established Bayesian model¹⁴⁶³ to estimate the probability of false matching an expended 9mm cartridge case from a semi-automatic pistol that did not fire it.

Wong¹⁴⁶⁴ tested the reproducibility of the Ruger P89 pistol by discharging 1 000 rounds of ammunition. He compared the firing pin aperture shear marks and land engraved areas of every 25th fired projectile and cartridge case to the first fired projectile and cartridge case. For the projectiles, small striation differences were observed, especially in the trailing edge of the land engraved areas. Even with the variation, every projectile could be identified to the first projectile fired by the same firearm. For the firing pin aperture shear marks, the degree of shearing and the quality of the marks were inconsistent, but the cartridge cases could still be identified to the first fired cartridge case.

Kirk *et al.*¹⁴⁶⁵ determined the estimation of change in breechface and firing pin marks over consecutive discharges and its impact on an IBIS Heritage System. In the study they discharged 5 000 rounds using 25 new Ruger SR9 pistols (200 rounds per pistol). They determined that no significant changes in the firearm surface occurred by looking at all breechface and firing pin marks through an IBIS Heritage system.

Although a small sample size of sources (firearms) were used over the years to determine their reproducibility, the results successfully support the hypothesis. Firearms do produce similar markings on cartridge cases and projectiles with consecutive discharging, however there is some

¹⁴⁶² Hamby JE *et al.* "Evaluation of GLOCK 9mm firing pin aperture shear mark individuality based on 1,632 different pistols by traditional pattern matching and IBIS pattern recognition" 2016 *J Forensic Sci* 61(1):170-176.

¹⁴⁶³ Schuckers ME "Interval estimates when no failures are observed. IEEE AutoID Conference Proceedings" 2002 *Tarrytown New York: Institute of Electrical and Electronics Engineers* 37-41.

¹⁴⁶⁴ Wong C "The inter-comparison of 1,000 consecutively-fired 9mm Luger bullets and cartridge cases from a Ruger P89 pistol utilizing both pattern matching and quantitative consecutive matching striae as criteria for identification" 2013 *AFTE J* 45(3):267-272.

¹⁴⁶⁵ Kirk J *et al.* "Estimation of changes in breechface and firing pin marks over consecutive discharges and its impact on an IBIS Heritage System" 2017 *Forensic Sci Int* 278:47-51.

variability when different materials are used during manufacturing. It was also determined that even when a firearm is disposed of into a fire, after recovery of the burned firearm, it still produces reproducible markings similar to those prior, by the burned source.^{1466,1467}

All the studies show an overwhelming support for the reproducibility of markings carried over from one single tool to multiple objects. However, these publications could rather be considered technical notes, rather than validation studies due to the lack of applied statistical models to determine validity and variability. Due to the absence of statistical knowledge by the majority of the researchers, many of these papers will not be accepted in peer-review journals as no statistical models were applied in support of their findings.

8.7.2 *Individuality of markings*

The second important aspect is to compare the markings on projectiles and cartridge cases discharged from consecutively manufactured firearms or parts thereof. To complete these studies, researchers had to reach out to manufacturers to obtain firearms or parts thereof in consecutively manufactured production lines.

This section will focus on some of those research studies contributing to the hypothesis that enough variation occurs on markings transferred to projectiles and/or cartridge cases to distinguish between consecutively manufactured firearms or parts of firearms.

Early studies on projectiles and barrels were conducted by Skolrood,¹⁴⁶⁸ comparing projectiles discharged from consecutively rifled Coeey .22 caliber barrels. Further research was done by

¹⁴⁶⁶ Marsanopoli JE *et al.* "The effects of fire damage on the ability to make identifications Part II: cartridge cases" 2008 *AFTE J* 40 (1):81-90.

¹⁴⁶⁷ Marsanopoli JE and Gerber KA "The effects of fire damage on the ability to make identifications Part III: comparison of burned firearms and ammunition components" 2009 *AFTE J* 41 (1):33-39.

¹⁴⁶⁸ Skolrood R "Comparison of bullets fired from consecutively rifled Coeey .22 Caliber Barrels" 1975 *Canadian Soc Forensic Sci J* 8(2):49-52.

Freeman¹⁴⁶⁹, Murdock¹⁴⁷⁰ and Hall¹⁴⁷¹ to prove individuality between projectiles fired from consecutively manufactured barrels. Matty¹⁴⁷² added additional steps to determine individual markings by comparing three revolver barrels, all cut from the same section of a rifled tube. He first examined Microsil casts of the barrels before discharging any projectiles through them. He observed no carry-over of subclass casts of lands, but longitudinal striations on the grooves caused by button imperfections were noticed. He was able to distinguish the uniqueness between the three barrels. Brundage,¹⁴⁷³ and Brown and Bryant¹⁴⁷⁴ continued in the mid-1990s with similar research and also discovered successful associations between consecutively manufactured barrels and projectiles discharged from them. Some subclass carry-over on the groove impressions on the projectiles was also discovered by Brown and Bryant.¹⁴⁷⁵

In 2016, Hamby *et al.*¹⁴⁷⁶ published their findings following their evaluation of 1 632 different 9mm GLOCK firing pin aperture shear marks. They used optical microscopy and electronic imaging technology with no misidentifications reported. They used the empirical findings to establish a Bayesian probability model and estimated that the random change of two different GLOCK 9mm pistols transferring similar aperture shear marks is less than 0.0001 %. A more recent paper by Hamby *et al.*¹⁴⁷⁷ involved a worldwide study of projectiles from 10 consecutively rifled 9mm Ruger pistol barrels to determine examiner error rates. The researchers wanted to determine whether examiners and researchers could accurately identify 15 unknown bullets obtained by discharging 10 consecutively rifled semi-automatic pistol barrels. Of the 10 455 unknown projectiles examined, three examiners reported insufficient individual characteristics for two of the projectiles and two trainee examiners failed to associate five unknown projectiles to the known projectiles. They

¹⁴⁶⁹ Freeman R "Consecutively rifled polygon barrels" 1978 *AFTE J* 10(2):40-42.

¹⁴⁷⁰ Murdock J "A general discussion of gun barrel individuality and an empirical assessment of the individuality of consecutively button rifled .22 Caliber Rifle Barrels" 1981 *AFTE J* 13(3):84-111.

¹⁴⁷¹ Hall E" Bullet markings from consecutively rifled Shilen DGA Barrels" 1983 *AFTE J* 15(1):33-47.

¹⁴⁷² Matty W and Johnson T "A comparison of manufacturing marks on Smith & Wesson Firing Pins" 1984 *AFTE J* 16(3):51-56.

¹⁴⁷³ Brundage DJ "The identification of consecutively rifled gun barrels" 1998 *AFTE J* 30(3):438-444.

¹⁴⁷⁴ Brown C and Bryant W "Consecutively rifled gun barrels present in most crime labs" 1995 *AFTE J* 27(3):254-258.

¹⁴⁷⁵ Brown Consecutively Rifled Gun Barrels 1995 [254-258].

¹⁴⁷⁶ Hamby J *et al.* "Evaluation of GLOCK 9 mm Firing Pin Aperture Shear Mark Individuality Based on 1,632 Different Pistols by Traditional Pattern Matching and IBIS Pattern Recognition" 2016 *J Forensic Sci* 61(1):170-176.

¹⁴⁷⁷ Hamby "Evaluation of GLOCK 9 mm" 2016.

reported it as inconclusive. Therefore, 10 448 of the unknown projectiles were correctly identified to the known projectiles provided to the examiners. There were no false positives or false negatives, which made it difficult to determine a true error rate. The authors credited the success of the results to the good condition of the discharged projectiles, and the quality of training modules provided by the NIJ.¹⁴⁷⁸

In three separate studies, Matty's¹⁴⁷⁹ research focused on three consecutively made breechfaces from Raven semiautomatic pistols¹⁴⁸⁰, and firing pins from Smith and Wesson K-frame revolvers¹⁴⁸¹ respectively. He concluded that the concentric markings on the cartridge breechfaces could be individualised and did not form part of any subclass markings. However, with the comparison of the firing pins, subclass carry-over features were detected due to the presence of random defects during the manufacturing machining process. Matty also compared projectiles discharged from three individual barrels produced from one button-rifled barrel blank. He noted subclass characteristics in the groove impressions, but not in the land impressions. He also reported significant changes on the striations from the first couple of fired projectiles.

Thompson¹⁴⁸² followed up on the research of Matty and compared four breechfaces from Phoenix pistols (formerly Raven), and confirmed the uniqueness of the identifying marks between them. Two years later, Thompson¹⁴⁸³ discovered that false breechface identifications are possible for Lorcin breechfaces, because they are stamped and then painted over and not machined.

Breechface comparisons using firearms with close related serial numbers (.25 Auto Browning pistol and .25 Auto Ravens pistol) were studied by Uchiyama.¹⁴⁸⁴ He reported significant subclass

¹⁴⁷⁸ National Institute of Justice. Training: firearms examiner training (account sign-up required); <http://firearms-examiner.training.nij.gov/> (Date of use: 14 November 2019).

¹⁴⁷⁹ Matty W "A Comparison of Three Individual Barrels Produced from One Button-Rifled Barrel Blank" 1985 *AFTE J* 17(3):64-69.

¹⁴⁸⁰ Matty W "Raven .25 Automatic Pistol Breechface Tool Marks" 1984 *AFTE J* 16(3):57- 60.

¹⁴⁸¹ Matty W Comparison of Manufacturing Marks 1984.

¹⁴⁸² Thompson E "Phoenix Arms (Raven) Breechface Toolmarks" 1994 *AFTE J* 26(2):134-135.

¹⁴⁸³ Thompson E "False Breechface ID's" 1996 *AFTE J* 28(2):95-96.

¹⁴⁸⁴ Uchiyama T "Similarity among Breechface Marks Fired from Guns with Close Serial Numbers" 1986 *AFTE J* 18(3):15-52.

carry-over among breechface marks produced by these firearms. Lardizabal¹⁴⁸⁵ examined the correspondence of breechfaces of three Heckler and Koch .40 Smith and Wesson pistols (two with sequential serial numbers and one random selected pistol with a lower serial number). He identified striated marks located above the firing pin that persisted over 250 discharged cartridges from the two closely related firearms, but similar marks were not present on the breechface of the third firearm.

Bonfanti and De Kinder¹⁴⁸⁶ published an article involving multiple scientific studies on projectiles and cartridge casings discharged from consecutive manufactured firearms. Miller^{1487,1488,1489} also published a number of papers to support individuality of markings from consecutively manufactured rifled barrels and the criteria for identification. Coody¹⁴⁹⁰ performed similar tests comparing breechfaces of 10 consecutively produced pistol slides of the Ruger P-89.

Bunch and Murphy completed an FBI study on 10 consecutively manufactured GLOCK semi-automatic pistol slides from Austria. A comprehensive validation study by members of the Firearm-Toolmark Unit examined the breechface markings and they were able to identify the discharged cartridges to their respective slides.¹⁴⁹¹

Lyons,¹⁴⁹² who studied ten consecutively manufactured extractors, reported that consecutively manufactured extractors could be distinguished from each other. In 2010, Lightstone¹⁴⁹³ experimented with consecutively manufactured Smith & Wesson pistol slides and looked at breechface markings left on the fired cartridge cases. She determined that some subclass

¹⁴⁸⁵ Lardizabal P "Cartridge Case Study of the Heckler and Koch USP" *1995 AFTE J 27(1)*:49-51.

¹⁴⁸⁶ Bonfanti M and De Kinder J "The Influence of the Use of Firearms on their Characteristics Marks" *1999 AFTE J 31(1)*:318-323.

¹⁴⁸⁷ Miller J "Criteria for Identification of Toolmarks, Part II: Single Land Impression Comparisons" *2000 AFTE J 32(2)*:116-131.

¹⁴⁸⁸ Miller J "An Examination of the Application of the Conservative Criteria for Identification of Striated Toolmarks Using Bullets Fired from Ten Consecutively Rifled Barrels" *2001 AFTE J 33(2)*:125-132.

¹⁴⁸⁹ Miller J and McLean M "Criteria for Identification of Toolmarks" *1998 AFTE J 30(1)*:15-61.

¹⁴⁹⁰ Coody AC "Consecutively Manufactured Ruger P-89 Slides" *2003 AFTE J 35(2)*:157-160.

¹⁴⁹¹ Bunch SG and Murphy D "A Comprehensive Validity Study for the Forensic Examination of Cartridge Cases" *2003 AFTE J 35(2)*:201-203.

¹⁴⁹² Lyons DJ "The Identification of Consecutively Manufactured Extractors" *2009 AFTE J 41(3)*:246-256.

¹⁴⁹³ Lightstone "Subclass Characteristics" 2010.

characteristics were present, but stated that experienced examiners will still be able to identify each fired cartridge to the correct pistol slide.

LaPorte¹⁴⁹⁴ conducted an empirical and validation study on breechface marks using consecutively manufactured .380 ACP caliber Hi-Point pistols and three different brands of ammunition. She also determined that the machining process resulted in unique and individual marks for identification on the breechfaces. A validation study on five consecutively manufactured slides from a 9mm Luger Hi-Point model C-9 pistol was conducted by Cazes and Goudeau.¹⁴⁹⁵ They utilised 68 trained examiners by providing them with two reference fired cartridge cases from each of the slides and eight questioned cartridge cases. They recorded a 100 % positive identification and a 0 % inconclusive rate by all the examiners. One key difference was the location of the firing pin aperture on the casings from the different slides.

Using the enhanced bullet identification system (EBIS), Fadul¹⁴⁹⁶ studied 10 consecutively manufactured Glock barrels. He distributed tests to 238 trained examiners from 150 laboratories. He received results from 183 participants with an error rate of 0.4 %. Two years later, Fadul *et al.*¹⁴⁹⁷ reported a less than 0.1 % error rate using 10 consecutive manufactured slides from a 9mm Luger Ruger. They provided 217 firearm examiners with two or more years of experience, two reference fired cartridge cases from each slide and 15 questioned cartridge cases. From the 3 255 breechface comparisons, 99.5 % were correctly identified, 0.06 % were false positives and 0.43 % reported as inconclusive. The authors' results showed that there were no significant differences between examiners with less or more than 10 years' experience, lightning methods, or type of microscope used.

¹⁴⁹⁴ LaPorte D "An Empirical and Validation Study of Breechface Marks" 2011 *AFTE J* 43(4):3303-309.

¹⁴⁹⁵ Cazes M and Goudeau, J "Validation Study Results from Hi-Point Consecutively Manufactured Slides" 2013 *AFTE J* 45(2):175-177.

¹⁴⁹⁶ Fadul TG "An Empirical Study to Evaluate the Repeatability and Uniqueness of Striations/Impressions Imparted on Consecutively Manufactured Glock EBIS Gun Barrels" 2011 *AFTE J* 43(1):37-44.

¹⁴⁹⁷ Fadul TG *et al.* "An Empirical Study to Improve the Scientific Foundation of Forensic Firearm and Tool Mark Identification Utilizing 10 Consecutively Manufactured Slides" 2013 *AFTE J* 45(4):376-393.

Using the confocal microscope to examine breechface marks on discharged cartridge cases from ten consecutively manufactured pistol slides, Weller *et al.*¹⁴⁹⁸ made a total of 8 010 microscopic comparisons with a 3D cross-correlation analysis logarithm. The study showed no overlap of scores between matching and non-matching test scores, with an average match score of 0.82 and an average non-match score of 0.20.

Mayland and Tucker studied¹⁴⁹⁹ obturation marks from reamed chambers of discharged cartridge casings from ten consecutively manufactured firearms. The empirical study included 64 examiners from 19 national laboratories, and results indicated that reliable identification can be made from obturation marks for the identification of cartridge casings fired from a specific firearm.

Another comparison study on class and individual characteristics was performed by Saribey and Hannam.¹⁵⁰⁰ They tested the hypothetical principle that it is impossible to manufacture two identical items at a microscopic level. In their study, they used two different makes of 7.65mm Browning/.32 caliber self-loading pistols of a Turkish manufacturer. They discharged ten rounds of ammunition of ten firearms with consecutive serial numbers. By observing firing pin impression, ejector, and breechface marks, they came to the conclusion that markings carried over from each firearm to cartridge casing are significantly different from one another.

Reliability and individuality were not the only concepts to establish the scientific foundation to support the first proposition. Other statistical approaches also contributed to a sound foundation of reliability.

All the studies referred to above in paragraphs 8.7.1 and 8.7.2 had one common goal: to provide a foundational basis upon which an identification in firearm and toolmarks is achieved. In the earlier

¹⁴⁹⁸ Weller TJ *et al.* "Confocal Microscopy Analysis of Breech face Marks on Fired Cartridge Cases from 10 Consecutively Manufactured Pistol Slides" 2012 *J Forensic Sci* 57(4):912-917.

¹⁴⁹⁹ Mayland B and Tucker C "Validation of Obturation Marks in Consecutively Reamed Chambers" 2012 *AFTE J* 44(2):167-169.

¹⁵⁰⁰ Saribey A and Hannam A "Comparison of the Class and Individual Characteristics of Turkish 7.65mm Browning / .32 Automatic Caliber Self-Loading Pistols with Consecutive Serial Numbers" 2012 *J Forensic Sci* 58(1):146-150.

articles, quantifiable numbers that the legal and scientific disciplines require to show scientific progress, were lacking. Nicolas¹⁵⁰¹ stated that all of the research that was conducted appear to be in part based on the scientific method, which tests hypotheses by experimenting and making observations. He claimed that the lack of some statistical numbers generated, does not make it less scientifically valuable. In 1995, Deschenes *et al.*¹⁵⁰² published their research regarding statistical values in toolmark comparisons. They stated that statistics do not allow the drawing of conclusions concerning a particular situation, and equally do not answer the question on the number of corresponding lines required to get a positive match. Taroni *et al.*¹⁵⁰³ critically responded to the work of Deschenes and argued that statistics do have a valuable place in patterned evidence identification. They argued that forensic scientists are unable to answer the totality of the judicial question (What are the odds that this tool has produced this toolmark given the circumstances of the case and the observations made by the examiner?) and therefore need statistical models to assist in those questions. They also added that statistics assess the validity of the scientific principles of the discipline and assist the examiner in coping with uncertainty. It is, therefore, important for the examiner and statistician to acknowledge each other's role in the process. In 2003, as Part II to his 1997 publication, Nicolas¹⁵⁰⁴ published another paper in which he again reviewed numerous articles and discussed their value to firearm and toolmark examinations. He argued that the newer publications articulate the basis and application of pattern evidence identification and the suitability of CMS within the discipline.

The next section will address some of the statistical approaches within the discipline.

8.7.3 *Other statistical approaches*

The discipline has seen many statistical approaches and theories as part of the objective for determining a more objective foundation to support subjective opinions. One of the first known

¹⁵⁰¹ Nicolas "Firearm and Toolmark Identification" 1997.

¹⁵⁰² Deschênes M *et al.* "Statistics and toolmarks comparisons" 1995 *AFTE J* 27(2):140–1.

¹⁵⁰³ Taroni F "Statistics: a future in toolmarks comparison?" 1996 *AFTE J* 28(4):222–9.

¹⁵⁰⁴ Nicolas "Firearm and Toolmark Identification" 2003.

probability studies on toolmarks was completed by May in 1930.¹⁵⁰⁵ He used various cutting tools, mostly knives, with working edges containing grinded finishes, to establish a statistical validation in toolmark identification. He calculated the probability of the same identifying marks appearing on another tool to be approximately 100,000 x 650 quadrillion (650×10^{16}). Hatcher *et al.*¹⁵⁰⁶ calculated that the probability of the same set of identifiable marks appearing on another tool was approximately 1 in 432 x10⁹ (100 million), but more than 40 years later, Heard¹⁵⁰⁷ claimed that number to be 1 in 52,86 x 10⁷ (one million).

Another theorem is the consecutive matching striae (CMS) approach. In CMS the individuality of striated toolmarks, based on the quantity of consecutively matching striae, was researched. Research approaches include theoretical, mathematical, and empirical studies. One of the earlier approaches may be credited to Biasotti,¹⁵⁰⁸ who studied the probability of occurrence of consecutive matching striae in land impressions from projectiles in both match and non-match positions. He concluded that:

“The most significant point of the data collected is the fact that 3 consecutive matching lines for lead bullets and 4 consecutive matching lines for metal-cased bullets appears to be the dividing line between data for same and different guns; and therefore, these critical series form the base line upon which the data for bullets from the same gun can be differentiated from the data for different guns.”

Therefore, the threshold number between known match and known non-match was established at 3 to 4 consecutive matching striae. Bunch¹⁵⁰⁹ later criticised the CMS approach for the lack of statistical (probabilistic) insight, such as Bayesian likelihood ratios.

¹⁵⁰⁵ May L “Identification of Knives, Tools and Instruments” 1930 *J Police Science (no volume or number listed)* 247-248.

¹⁵⁰⁶ Hatcher *Firearm Investigation Identification and Evidence* 1957 [380].

¹⁵⁰⁷ Heard BJ *Handbook of Firearms and Ballistics* (Wiley & Sons 1997).

¹⁵⁰⁸ Biasotti A “A Statistical Study of the Individual Characteristics of Fired Bullets” 1959 *J Forensic Sciences* 4(1):34-50.

¹⁵⁰⁹ Bunch SG “Consecutive Matching Striation Criteria: A General Critique” 2000 *J Forensic Sci* 45(5):955-962.

Brackett¹⁵¹⁰ followed a mathematical model approach that could be used in the study of “idealised” striated marks, which included geometric-, number-based-, random number outcome-, and random number replica models. This would establish a theoretical basis for striated mark analysis, which in return would support empirical models to obtain sufficient information to establish objective criteria to provide identification between two sets of marks. He concluded that from all the different models explored, the development of a random number table would be the best to represent a reliable striated toolmark model. Although his work was not explored further, the concept of consecutiveness was a useful tool in deciphering coincidence from common association. At the time, the mathematical models were tedious, but it could become more practical with the development of computer software in the future. A simulation study of striated marks was conducted by Blackwell and Framan,¹⁵¹¹ who applied Brackett’s models. They determined that the models were reliable and in agreement with each other. The results were also in agreement with the results of Biasotti’s empirical studies.¹⁵¹²

Uchiyama published two papers, one on the development of a criteria for identification of land impressions using probability theory with a developed associated significance level.¹⁵¹³ He noted in his conclusion that consecutiveness of matching striae plays an integral part in indicating the identity of projectiles from the same source. His second paper¹⁵¹⁴ provided an estimate of the number of consecutively corresponding lines expected, while considering striae density, critical coincidence ratio and striae width. His results closely resonated with Biasotti’s original empirical work, with a maximum of 3 to 4 consecutive lines that would represent a known non-match.

In 1997, Biasotti *et al.*,¹⁵¹⁵ editors of a chapter in “Firearm and Toolmark Identification: Modern Scientific Evidence: The Law and Science of Expert Testimony”, proposed a conservative

¹⁵¹⁰ Brackett J “A Study of Idealized Striated Marks and Their Comparison Using Models” 1970 *J Forensic Sci Soc* 10(1):27-56.

¹⁵¹¹ Blackwell R and Framan E “Automated Firearms Identification System (AFIDS): Phase I” 1980 *AFTE Journal* 12(4):11-37.

¹⁵¹² Biasotti “Individual Characteristics” 1959.

¹⁵¹³ Uchiyama T “A Criterion for Land Mark Identification” 1988 *AFTE J* 20(3):236-251.

¹⁵¹⁴ Uchiyama T “The Probability of Corresponding Striae in Toolmarks” 1992 *AFTE J* 24(3):73-290.

¹⁵¹⁵ Biasotti A *et al.* “Modern Scientific Evidence: The Law and Science of Expert Testimony” (St. Paul: West 1997 – Chapter 23 *Firearms and Toolmark Identification* 1997).

numerical criterion based on counting runs of consecutive matching striae. These conservative quantitative criterion were the following:

“In three dimensional toolmarks when at least two different groups of at least three consecutive matching striae appear in the same relative position, or one group of six consecutive matching striae are in agreement in an evidence toolmark compared to a test toolmark.”

“In two dimensional toolmarks when at least two groups of at least five consecutive matching striae appear in the same relative position, or one group of eight consecutive matching striae are in agreement in an evidence toolmark.”

“For these criteria to apply, however, the possibility of subclass characteristics must be ruled out.”¹⁵¹⁶

Neel and Wells¹⁵¹⁷ studied 4 000 striated toolmark comparisons to statistically distinguish between known matches and known non-matches and calculated a likelihood ratio of 1 in 802 919 using 3D images and a 1 in 12 090 164 in 2D images.

Using an effective correlation area based method, Yammen and Muneesawang¹⁵¹⁸ demonstrated that cartridge case image matching through this method had a high discriminative power.

Estimates of coincidental match probability to specify uncertainty of DNA identification were explored since the 1980s. In this regard, the NRC report observes that “[...] courts already have proven their ability to deal with some degree of uncertainty in individualizations, as demonstrated by the successful use of DNA analysis (with its small, but nonzero, error rate).”¹⁵¹⁹ Similar scientific foundations and statistical procedures to provide quantitative error rate were expected to support firearm identifications. Computer learning approaches to accomplish some of the rates required,

¹⁵¹⁶ Biasotti “Expert Testimony” 1997.

¹⁵¹⁷ Neel M and Wells M “A Comprehensive Statistical Analysis of Striated Tool Mark Examinations Part I: Comparing Known Matches and Known Non-Matches” 2007 *AFTE J* 39(4):176-198.

¹⁵¹⁸ Yammen S and Muneesawang P “Cartridge case image matching using effective correlation area based method” 2013 *Forensic Sci Int* 229:27-42.

¹⁵¹⁹ NAS *Report* 2009 [153-155] [184].

were studied by Petraco *et al.*^{1520,1521} The statistical study evaluated 3D quantitative surface topographies of toolmarks using a confocal microscope. Estimated toolmark identification error rates were approximately 1 per cent using the applied algorithmic methods. Riva and Champod¹⁵²² researched likelihood ratios, Lilien^{1523,1524} considered feature-based matching algorithms, Song *et al.*^{1525,1526,1527,1528,1529,1530,1531} studied image cross correlation and congruent matching cells (CMC), whereas Hare *et al.*¹⁵³² followed the random forest approach.¹⁵³³

Persistent and characteristic features in firearm tool marks on cartridge cases were identified by Ott *et al.*¹⁵³⁴ Ghani *et al.*¹⁵³⁵ analysed 48 initial features of 747 cartridge case images discharged by five different firearms using geometric imaging moments (MANOVA test). By using correlation

¹⁵²⁰ Petraco NDK and Chan H “Application of Machine Learning to Tool Marks: Statistically Based Methods for Impression Pattern Comparisons” *NIJ Report 239048, National Institute of Justice, Washington, DC, 2012.*

¹⁵²¹ Petraco NDK *et al.* “Estimates of striation pattern identification error rates by algorithmic methods” *2013 AFTE J 45(3):235–244.*

¹⁵²² Riva Automatic comparison 2014.

¹⁵²³ Lilien R “Applied Research and Development of a Three-dimensional Topography System for Firearm Identification Using GelSight” *NIJ Report 248639, National Institute of Justice, Washington, DC, 2016.* <https://www.ncjrs.gov/pdffiles1/nij/grants/248639.pdf>.

¹⁵²⁴ Kerkhoff W *et al.* “The likelihood ratio approach in cartridge case and bullet comparison” *2013 AFTE J 45(3):284–289.*

¹⁵²⁵ Song J *et al.* “SRM 2460/2461 standard bullets and cartridge cases project” *2004 J Res Natl Inst Stand Technol 109(6):533–542.*

¹⁵²⁶ NIST SRM 2460/2461 Standard Bullet and Cartridge Cases, Available at <http://www.nist.gov/pml/div683/grp02/sbc.cfm> (updated, May 25, 2017). (Date of use: 18 November 2019).

¹⁵²⁷ Song J “Proposed NIST ballistics identification system (NBIS) using 3D topography measurements on correlation cells” *2013 AFTE J 45(2):184–189.*

¹⁵²⁸ Song J “Proposed ‘congruent matching cells (CMC)’ method for ballistic identification and error rate estimation” *2015 AFTE J 47(3):177–185.*

¹⁵²⁹ Chu Validation tests for the congruent matching cells 2013.

¹⁵³⁰ Tong M *et al.* “Fired cartridge case identification using optical images and the congruent matching cells (CMC) method” *2014 J Res Natl Inst Stand Technol 119:575–582.*

¹⁵³¹ Song J *et al.* “Estimating error rates for firearm evidence identifications in forensic science” *2018 Forensic Sci Int 284:15–32.*

¹⁵³² Hare E *et al.* “Automatic matching of bullet land impressions” *2017 Ann Appl Stat 11 (4):2332–2356.*

¹⁵³³ Ho TK “Random Decision Forests” *Proceedings of the 3rd International Conference on Document Analysis and Recognition, Montreal, QC, 14–16 August 1995 [278–282].* Random forests or random decision forests are an ensemble learning method for classification, regression and other tasks that operates by constructing a multitude of decision trees at training time and outputting the class that is the mode of the classes or mean prediction of the individual trees.

¹⁵³⁴ Ott D *et al.* “Identifying persistent and characteristic features in firearm tool marks on cartridge cases” *2017 Surface Topography: Metrology and Properties 5.*

¹⁵³⁵ Ghani NA *et al.* “Analysis of Geometric Moments as Features for Firearm Identification” *2010 Forensic Sci Int 198 (1):143-149.*

analysis, they reduced the high number of features into 11 significant features. They reported a 96.7 % success rate on classifying images correctly after using cross-validation under discriminant analysis.

Brunch and Wevers¹⁵³⁶ suggested a fundamental change from a concluding inconclusive or categorical opinion to a reflection of the evidential value under two hypotheses following Bayesian inference. Following up on this study, Wevers *et al.*¹⁵³⁷ examined a model that will increase objectivity on interpretation by using both consecutively matching striae (CMS) and Bayesian inference. Using this model showed some separation between known match and known non-match conditions. They suggested more studies of data to improve the incomplete model.

A statistical tool for forensic analysis of toolmarks was introduced by Baldwin *et al.*¹⁵³⁸ The basis of the statistical tool relied on discriminatory criteria that examiners utilised to identify features and spatial relationships in their examinations of samples.

Using a database of 3D striation patterns and applying algorithmic methods (principle component analysis and support vector machine methodology), Petraco *et al.*¹⁵³⁹ studied error rates of toolmarks (standard tip screwdrivers and firing pin apertures). They concluded that when enough data points are used to train the algorithm, identification error rates of less than 1 per cent were observed.

The implementation of a likelihood ratio approach of firearm identification was introduced by Kerkhoff *et al.* (Netherlands Forensic Institute).¹⁵⁴⁰

¹⁵³⁶ Bunch S and Wevers G "Application of likelihood ratios for firearm and toolmark analysis" 2013 *Sci & Justice* 53(2):223-229.

¹⁵³⁷ Wevers G *et al.* "A Comprehensive Statistical Analysis of Striated Toolmark Examinations Part 2: Comparing Known Matches and Known Non-Matches using Likelihood Ratios" 2011 *AFTE Journal* 43(2):137-145.

¹⁵³⁸ Baldwin D *et al.* "Statistical Tools for Forensic Analysis of Tool marks Ames (IA)" 2004 *Ames Laboratory Technical Report IS-5160*.

¹⁵³⁹ Petraco Estimates of Striation Pattern Identification 2013.

¹⁵⁴⁰ Kerkhoff "The Likelihood Ratio Approach" 2013.

Researchers at the NIST proposed an error rate procedure based on the congruent matching cell (CMC) method, which will in turn establish a statistical foundation to support objective identifications and provide an error rate report for court proceedings. The report would be similar to reporting random match probability for DNA evidence. Their first study on error rate values were at likelihood ratios of 10^{-6} or less.¹⁵⁴¹

Through the studies referred to above, a statistical foundation has been laid for the first proposition stipulated by the FBI, namely, (1) reproducibility of markings, and (2) individuality of markings. However, less attention has been given to support the second proposition, namely testing the examiner to determine how many false positives and false negatives will contribute to the human error rate. One way to establish such error rate is through “black box” studies, already discussed in chapter six relating to fingerprint evidence. Without repeating what was stated in chapter six, the next section will relate “black box studies” to the context of firearm and toolmarks.

8.7.4 *Black box studies*

The purpose of “black box” studies is to establish a validity test where errors from all possible sources would be included into the final test outcome. The errors directly test the validity of the firearm and toolmark discipline and the proposition that trained examiners are able to distinguish similarities and dissimilarities between objects from the same source or different sources. A number of these tests were completed under the control of the FBI.^{1542,1543,1544,1545}

Bunch and Murphy¹⁵⁴⁶ highlighted a number of key elements when conducting such tests:

- Examiners must be anonymous.

¹⁵⁴¹ Song “Proposed Congruent Matching Cells” 2015.

¹⁵⁴² Bunch “Comprehensive Validity Study” 2003.

¹⁵⁴³ DeFrance C and Van Arsdale M “Validation study of electrochemical rifling” 2003 *AFTE J* 35(1):35-37.

¹⁵⁴⁴ Giroux B “Empirical and validation study: consecutively manufactured screwdrivers” 2009 *AFTE J* 41(2):99-110.

¹⁵⁴⁵ Smith E “Cartridge case and bullet comparison validation study with firearms submitted in casework” 2005 *AFTE J* 37(2):130-135.

¹⁵⁴⁶ Bunch and Murphy “Validation study” 2003.

- Examination must be conducted without examiners knowing it is a “test” (Blind test)
- Once a participant enrolled in the blind testing, result must be returned to the researchers.
- No unambiguous responses, which means participants had to be certain about their results, without any doubts.
- Examiners must be qualified and trained in the field of firearm and toolmark examinations.

Another form of a black box study is using proficiency tests which test the examiners’ competence and not the validity of the technique. It is more of a self-assessment test for laboratories as part of a quality control mechanism, but with built in corrective action procedures when errors are identified. Sections 7.6.1 and 7.6.2 of this chapter referred to a number of studies where experts examined the similarities and dissimilarities between discharged projectiles and cartridge cases, and the source of discharge. Although success with low error rates was determined, variabilities between discharged objects (projectiles and cartridge cases) could not be established, as the quality between them either provided a good image for comparison, whereas others provided a bad quality image.

A study on error rates between examiners, with false positive rates of 1.01 % and false negative rates of 0.0367 %, was performed by Baldwin *et al.*¹⁵⁴⁷ A validation study using actual casework samples was performed by Smith *et al.*¹⁵⁴⁸ They randomly selected sets of ammunition to create variability in each test packet that was sent out to experienced examiners. They reported a false positive rate of 0.144 % and a false negative rate of 0.433 % on cartridge casings, and a 0.0% false positive rate and 0.105 % false negative rate on projectiles. They maintained that this study represented a realistic assessment of a trained examiner’s ability to reach conclusions of identification and exclusion.

Researchers were faced with other challenges due to the fact that examiners did not look at exactly the same evidence when performing comparisons. Two ways to overcome the problem is to either

¹⁵⁴⁷ Baldwin DP *et al.* “A Study of False-Positive and False-Negative Error Rates in Cartridge Case Comparisons” 2014 *Ames Laboratory USDOE Technical Report IS-5207 April 7.*

¹⁵⁴⁸ Smith TP *et al.* “A Validation Study of Bullet and Cartridge Case Comparisons Using Samples Representative of Actual Casework” 2016 *J Forensic Sci* 61(4):939-946.

replicate a discharge cartridge in the form of moulds of that cartridge or distribute them to examiners as blind proficiency tests, or to image the original discharged cartridge through a 3D scanner and provide examiners with virtual microscopy viewer software when examining the evidence. The second option will be discussed under future developments later in this chapter.

In 2017, the NIJ funded one such research initiative at Cadre Research Labs, LLC. The study was called, “Firearm Forensics Black-Box Studies for Examiners and Algorithms using Measured 3D Surface Topographies”.¹⁵⁴⁹ The researchers developed a TopMatch-3D system based on imaging technology that uses a thin electrometric gel to produce accurate measurements of microscopic surface features. They also developed a specialised image matching algorithm to automatically detect and compare 3D impressions on the surface. They also created desktop and portable 3D scanners that can be used in the crime laboratory or at a crime scene for faster analysis. Recently, they partnered with Collaborative Testing Services (CTS), one of the largest proficiency test providers to all forensic disciplines.¹⁵⁵⁰

8.8 First challenges where the law challenged the scientific method

From the early days of firearm evidence, the legal challenge was to get the evidence admissible in court through testimony by an expert. Although the *Frye test* was the first test to set a foundation for the admissibility of expert scientific evidence in 1923, other cases relating to firearm evidence were admitted prior to this date.

In 1902, a Massachusetts State (USA) Court admitted the testimony of an expert on the effects of rifling and other markings in a firearm barrel upon projectiles discharged through the barrel. This was a breakthrough case in firearm and toolmark evidence, allowing the visual introduction through images of evidence and test-fired projectiles.¹⁵⁵¹ This testimony was a prelude to the concept of individuality of rifled barrels and became a fundamental concept in forensic ballistics.

¹⁵⁴⁹ National Institute of Justice, Award 2017-IJ-CX-0024, 2017 “Firearm Forensics Black-Box Studies for Examiners and Algorithms using Measured 3D Surface Topographies”

¹⁵⁵⁰ National Institute of Justice, Success Story: Advancing 3D Virtual Microscopy for Firearm Forensics, 6 March 2019. <https://nij.ojp.gov/library/publications/success-story-advancing-3d-virtual-microscopy-firearm-forensics> (Date of use: 18 November 2019).

¹⁵⁵¹ *Commonwealth v. Best* 180 Mass., 492, 62 N.E. 748.

In 1903, in London, England, Mr. E. J. Churchill testified on distance determination examinations that he had performed between a discharged firearm and wounds into a human skull. The testimony was in relation to the shooting death of Mrs. Camille Holland of Essex, England in 1899. After recovering her body, he examined her skull and determined that the cause of death was a short range single shot into her head with a .32-calibre revolver. E. J. Churchill used the same revolver and type of ammunition on a sheep's skull to successfully compare similarities in distance and size of the fatal wound in Mrs. Holland's head. The accused was subsequently convicted and hanged, based on the ballistic evidence.

In 1907, the US Army published their annual report of the Chief of Ordnance. Part of the annual report contained a report titled "Study of the Fired Bullets and Shells in Brownsville, Texas, Riot". A study focused on an incident involving several soldiers from a nearby U.S. Army Infantry Regiment, who allegedly fired some 150 to 200 shots from their assigned rifles throughout the entire town as part of a riot. Recovered cartridge cases and bullets, as well as rifles were sent to the staff of Frankfort Arsenal for their examination. They were able to identify 33 of the fired cartridge cases as having been fired from four of the submitted rifles. The report was the first recorded instance of fired cartridge cases being evaluated as evidence.¹⁵⁵²

Another major event in firearm identification was the examination of evidence recovered in the investigation of the Brownsville, Texas affray in 1907.¹⁵⁵³ The examiners Hawkins and Spooner, employed at the Springfield Armory, compared 33 expended cartridge cases and six unfired cartridges, with 279 rifles submitted to them. They were later asked to compare an additional 210 rifles with the evidence cartridge cases. They determined that three of the rifles were responsible for 30 of the cartridge cases, and a fourth rifle was probably responsible for the remaining three

¹⁵⁵² Edward E "Firearms and Fingerprints" [32].

¹⁵⁵³ Committee of Military affairs, U.S. senate, Affray at Brownsville Texas (Washington, D.C.: Government Printing office, 1907. The event involved the riot of some members of a U.S Infantry Regiment, stationed at Brownsville, Texas. One citizen was killed and another severely injured in the indiscriminate shooting that occurred, and the event gained national publicity. The responsible were never identified. However, all of the black enlisted personnel of the unit were dishonorably discharged following hearings on the matter.

cartridge cases. They also excluded the Mauser rifles and confirmed that the cartridge cases were fired from U.S. Military models. Hawkins and Spooner exercised great care in the enumerating and illustrating by drawing the individualising characteristics which formed the basis of their opinions. The mystery that was never answered was what the source of the techniques they used for the examination conducted was. There is also no record of their work before or after the Brownsville affray. An additional unusual feature was that Hawkins included in his first report probability estimates which related to the individualising characteristics which had been used during the comparisons.¹⁵⁵⁴

In 1915, in New York State (USA), the notorious ‘Stielow’ case was heard, known for the gross injustice that resulted. Stielow, an illiterate tenant farmer, allegedly shot and killed his employer and housekeeper. The housekeeper was able to run away after being shot, but was found dead near Stielow’s house. Most of the evidence was destroyed by a curious crowd due to the lack of experience of local authorities investigating the homicide. The firearm examiner, hired by the local authorities, immediately stated that a revolver found in Stielow’s house was used for the fatal shots. He alleged he found 9 abnormal striation marks on the fatal bullets during his testimony. Stielow was convicted of murder and sent to the state prison to await execution.

However, the Governor of the State, unsatisfied with the entire investigation, ordered a special investigation and engaged individuals to reinvestigate the case. New experts from the New York Attorney General’s Office were assigned. Mr. Charles E. Waite, in conjunction with Dr. Max Poser, a microscopy expert with Bausch and Lomb, microscopically examined the fatal bullets and revolver and determined the first observations made were not correct. Stielow was pardoned and released from prison.¹⁵⁵⁵

¹⁵⁵⁴ United States. Congress. Senate. Committee on Military Affairs “Affray at Brownsville, Tex, Volume 5” 1980 Washington 311-1322.

https://books.google.com/books?id=Y2QoAAAAyAAJ&pg=PA1310&lpg=PA1310&dq=Hawkins+and+Spooners+firearm+comparisons&source=bl&ots=qKuGViAcnV&sig=ACfU3U1bbsoY3PjCe2Kg209E08brxljMzA&hl=en&sa=X&ved=2ahUKEwi1xsq0rZ_nAhXzmXIEHXfcAw0Q6AEwCXoECAkQAQ#v=onepage&q=Hawkins%20and%20Spooners%20firearm%20comparisons&f=false (Date of use: 24 January 2020).

¹⁵⁵⁵ National Registry of Exonerations, Charles Stielow, Researched by Kerry Ford Cunningham. <https://www.law.umich.edu/special/exoneration/Pages/casedetailpre1989.aspx?caseid=312> (Date of use: 16 May 2019).

In 1920, Nicola Sacco and Bartolomeo Vanzetti were accused of shooting a factory worker who carried the payroll in Dedham, Massachusetts. The trial had four firearm experts, two testifying for the prosecution and two for opposing counsel. They were disagreeing with one another throughout the trial with regard to the uniqueness of the markings on the projectiles found on the scene. In the end, due to testimony from the prosecution, as well other testimony presented, resulted in both Nicola and Bartolomeo being found guilty and executed several years later for the crime. Some community members objected to both the trial and execution as they believe the accused were framed for their political views and that the firearm evidence was unreliable. On April 9, 1927, Sacco and Vanzetti's final appeal was rejected, and the two men were sentenced to death. In 1961, Frances Russell, a Boston author was convinced the two men were innocently executed,¹⁵⁵⁶ convinced two well-known examiners, Frank Jury, and Jac Weller, who had revised Hatcher's textbook,¹⁵⁵⁷ published in 1957, to re-examine the firearm evidence that killed the guard. They re-confirmed the results after test firing the firearm of Sacco and examining the bullets.¹⁵⁵⁸ This case demonstrates the consistency of striation marks over a period of 34 years.

In 1922, Paul Hadley from Tucson, Arizona was looking for a ride on November 1921 and was picked up by an elderly couple. Harley allegedly shot both individuals, killing one and wounded the other. He was later arrested and had a .32 calibre Mauser pistol and cartridges in his possession. The prosecuting attorney requested to whether the pistol could be connected to the fatal shootings. Mr. A. J. Eddy, a practicing attorney with some experience in the field of firearm examination was tasked to perform the examinations and determined that there was distinctive markings on the projectiles originating from the Mauser pistol. He conducted a number of test fires with the firearm in question as well as other .32-calibre firearms, and requested a local photographer to image the distinct markings. He was permitted to testify on his findings and provided extensive testimony

¹⁵⁵⁶ Gallo PJ "*The American Paradox: Politics and Justice*" (Howard University press 2001). "By modern standards none of these opinions was worth very much. The comparison microscope, which enables experts to make such judgments with a high degree of certainty, had not yet been developed, and forensic ballistics as practiced in 1921 was far from an exact science."

¹⁵⁵⁷ Hatcher Firearms investigation 1957.

¹⁵⁵⁸ Shannon WV "The show trial of Sacco & Vanzetti" 1986-01-26 *The Washington Post*.
https://www.washingtonpost.com/archive/entertainment/books/1986/01/26/sacco-38/76fb480b-89db-428c-9f08-4b744d95fe0e/?utm_term=.8e3e6efdefaa (Date of use: 20 November 2019).

concerning the elaborate tests that he had conducted and to prove to the jury that each pistol left its own distinctive characteristic markings on projectiles. However, the expertise of Eddy was questioned by the opposing counsel, but the judge overruled their request by stating that Eddy was only sharing his results from his research and experimental work with the court. The judge characterized the testimony as being that of a “semi-expert” and allowed Eddy’s testimony. Hadley was convicted on both charges of murder and attempted murder, the decision was in large part to Eddy’s testimony. The case was appealed to the Arizona Supreme Court and, after careful deliberation, upheld the lower court’s judgement. It was a historic and momentous decision, by recognizing firearm and toolmark evidence as valid and admissible. It was seen as the first ruling of a State Supreme Court in the United States setting a standard for admissibility of such evidence.¹⁵⁵⁹

In 1925, in the case *State v. Harold Israel*,¹⁵⁶⁰ the state prosecutor dismissed the prosecution of a suspect in a murder trial after six expert witnesses testified that the bullet recovered from the victim could not be compared to projectiles recovered from the pistol of the accused. The court record reflects, in some detail, the principles of firearms identification as known at that time, by means of enlarged photographs of comparisons. The court made the following statement regarding the state attorneys:

“The court has given very close attention to the state’s attorney and followed the presentation of the case as closely as it could. It is perfectly evident that a great deal of painstaking care has been expended on this case and that the attitude of the state’s attorney’s office has been what it always should be, one of impartiality and a desire to shield the innocent as well as a determination to prosecute those who are guilty.”¹⁵⁶¹

On February 14, 1929, in Chicago, Illinois (U.S.), four men hired by Al Capone entered a garage and ordered seven men inside to form a line against a brick wall. All seven men, henchmen of the infamous Chicago mobster George “Bugs” Moran, were gunned down by the four men, two

¹⁵⁵⁹ Good M “1923: Paul Hadley” 2014-04-13 *ExecutedToday.com*.

<http://www.executedtoday.com/2014/04/13/1923-paul-hadley/> (Date of use: 10 October 2019).

¹⁵⁶⁰ Cummings HS “1925, *State v. Harold Israel*” *Journal of Criminal Law and Criminology* Volume 15 Issue 3 Article 9.

¹⁵⁶¹ Cummings HS, 1925, *State v. Harold Israel*, [434].

dressed as police officers using Tommy firearms. The police raided Fred “Killer” Burke’s house and found firearms suspected of being used in the massacre. Burke pleaded his innocence at the time. Since the firearms were the main evidence connecting him to the crime, they sent the evidence to Calvin H. Goddard, a former physician and pioneer in the new field of “forensic ballistics”. Goddard test-fired the firearms recovered from Burke’s house and, by using a “split-image” comparison microscope invented for the purpose, matched grooved marks left on the projectiles and casings to those on projectiles and casings found at the crime scene. He acquitted any police involvement in the shooting and killing of seven gang members. For his great work and success during the trial, the grand jury foreman Mr. B.A. Masee and other public citizens provided funds for Goddard to build a forensic laboratory facility in Chicago. It was called the Scientific Crime Detection Laboratory (SCDL), where Goddard served as Director until 1934.

The 1960s were well known for a series of assassinations by using firearms, most notably in November 1963, the President of the United States, John Fitzgerald Kennedy, and in April 1968, Dr. Martin Luther King, Jr., an active civil rights proponent in the United States. In June 1968, Senator Robert Kennedy, the brother of President Kennedy, was assassinated. Courts heavily relied on firearm identification evidence for the convictions of the assassins.

In 1973, a new set of rules was laid down through the Federal Rules of Evidence (FRE702),¹⁵⁶² adopted by the federal court system in the United States. It set clear rules to every discipline in forensic science and required better knowledge, skills, experience, training, or education for examiners who wish to testify as an expert. It required experts to provide testimony based upon sufficient facts or data, base opinions on reliable principles and methods, and apply those principles and methods reliably to the facts of the case.

In 1975, Paul Schrade (one of the shooting victims) and CBS, Inc., (a nation-wide television broadcaster) petitioned to the Superior Court of California, County of Los Angeles to re-examine firearm evidence surrounding the killing of Senator Kennedy. The petition was granted by the court and ordered the formation of a panel of experts to conduct the re-examination. The American

¹⁵⁶² Federal Rules of Evidence “Rule702 – Testimony by Expert Witnesses” 2019 Edition.

Academy of Forensic Sciences (AAFS) and the Association of Firearm and Toolmark Examiners (AFTE) were requested to submit names of experienced firearms practitioners to the Attorney General of the State of California. Seven experts were selected and concluded that: “[t]here is no evidence to indicate that more than one gun was used to fire the items examined”.¹⁵⁶³

During 1977 and 1978, a selected group of experienced firearms examiners also re-examined firearms-related evidence pertaining to the following previous investigations:

- The assassination of President John F. Kennedy
- The murder of Police Officer J. D. Tippit
- The murder of Lee Harvey Oswald
- The assassination of Doctor Martin Luther King, Jr.

These re-examination of evidence was a result of public outcry for additional answers into the events cited. The United States House of Representatives assembled the Select Committee on Assassinations to conduct examinations of the firearms-related evidence. The group of examiners presented testimony of their results before the Select Committee investigating the assassinations of President Kennedy and Doctor King, and the murders of Officer Tippit and Mr. Oswald. Their testimony verified the findings of the original firearms examiners.¹⁵⁶⁴

In 1884 in the case of *Tesney v. State*,¹⁵⁶⁵ the question was raised if the defendant was shot at close range before stabbing the deceased in self-defence. The court admitted in making an error to admit evidence of a single experiment by firing at a similar coat worn by the deceased in order to show that no powder would be produced by a shot at close range. The court stated that:

“Such evidence super induces the mischief of trying a collateral controverted matter by providing separate and distinct experiments with results as variant as the manner of loading

¹⁵⁶³ Ayton M *The Forgotten Terrorist: Sirhan Sirhan and the Assassination of Robert F. Kennedy* (Potamic books 2007).

¹⁵⁶⁴ National Archives, <https://www.archives.gov/research/jfk/select-committee-report/summary.html> (Date of use: 4 January 2019).

¹⁵⁶⁵ *Tesney v. State*, (1884), 77 Ala. 33.

the pistols, and the modes of making the experiments dependent more or less on the wishes and feeling of the person making them, and tends to confuse the jury and withdraw their minds from the consideration of the main issue.”

The United States Supreme Court changed a legal standard for those providing scientific testimony (including expert testimony for firearms and toolmark identification) in Federal Courts, and some state courts, in 1993. The new standard, referred to in the United States as the ‘Daubert’ ruling, required trial judges to be the ‘gatekeepers’ of expert evidence. The ‘Daubert’ court set four criteria (not all-inclusive) which must evaluate scientific testimony before it can be admitted. The criteria are: (1) Testability of scientific principle; (2) Known or potential error rate; (3) Peer review and publication; and (4) General acceptance in a particular scientific community.

The new standard generated a significant amount of dialogue within the firearms examiner community, as it essentially required examiners to explain how conclusions are reached during and after examinations. Published findings of scientific research in peer reviewed journals, such as the AFTE Journal, were considered as one way of meeting criteria three, mentioned in the previous paragraph. Following the *Daubert* ruling, there had been a significant amount of research conducted and reported on in the AFTE Journal.

In 1997, attorneys working to exonerate James Earl Ray (now deceased), petitioned the court to reopen the assassination case of Dr. King. In their petition they stated that ‘new ground-breaking technology’ emerged over time that might change previous results obtained in 1968 and 1977. Previous examinations were conducted in 1968 by firearms examiners of the FBI Laboratory Firearms Unit, and in 1977 by a panel of firearms examiners who testified before the Select Committee of the House of Representatives.¹⁵⁶⁶ The ‘new’ technology — Scanning Electron Microscopy (SEM) and fiber optic lighting — was not available to the previous examiners who conducted the examinations at the time. A search of the literature reveals the use of SEM in firearms identification research prior to 1972, while a list of equipment used by the King panel

¹⁵⁶⁶ Billings R “James Earl Ray has already had his day in court” 1997-03-02 *The Washington Post*.

members in 1977 lists fiber optics lighting as being part of one of the comparison microscopes used for the reexamination.¹⁵⁶⁷ The request to reopen the case was denied by the court.

In 1997, in *U.S. v. Moore* in a *Frye* hearing, the defence motion contended that bunter tool identification, on cartridge headstamps, is not generally accepted in the scientific community. However, Judge Susan Winfield of the Superior Court of the District of Columbia noted that a previous *Frye* ruling supported the acceptance of such identification in the scientific community.¹⁵⁶⁸

Since the 1993 'Daubert' legal ruling by the US Supreme Court, and especially after 2000s, there have been a number legal challenges to all feature impression evidence disciplines, which include firearm and toolmark identification; questioned documents examination and latent print identification.

These challenges were made as part of the 'Daubert' ruling and the expectation by the larger community that all forensic science disciplines should be similar in value as DNA analysis. In some court hearings, the courts have ruled that the firearms examiner could provide their testimony but not provide an 'opinion'.¹⁵⁶⁹ This was due, in part, to a lack of a probable foundation on the part of

¹⁵⁶⁷ Hamby JE History of firearm and toolmark 1999.

¹⁵⁶⁸ Grzybowski RA and Murdock JE "Firearm and Toolmark Identification- Meeting the Daubert Challenge" 1998 *AFTE J* 30(1):187-251.

¹⁵⁶⁹ *Commonwealth v. Pytou Heang*, 458 Mass. 827, 2010; Court offered recommendations for future cases: "Require adequate documentation, Basis of opinion, avoid practical impossibility/certainty"; *United States v. Cerna* (N.D. Cal. 2010) Slip WL 3448528; "The court limited the firearms examiner to testifying to a "reasonable degree of certainty"; *U.S. v Willock* (D.Md. 2010) 696 F.Supp.2d 536 "(1) that the government must provide bases and reasons that support the opinion which includes the sketches, diagrams, notes, and photographs that the accepted methodology for application of the AFTE theory requires that the firearms examiner make; (2) firearms toolmark identification evidence is only relevant, reliable, and helpful to a jury if it is offered with the proper qualifications regarding its accuracy. (Note- the court adopted the recommendations made by the Magistrate in *Mouzone*"); *U.S. v. Mouzone* (2009), Criminal No. WDQ-08-086. (D. Md. Oct. 29, 2009), 1) That Sgt. Ensor not be allowed to opine that it is a "practical impossibility" for any other firearm to have fired the cartridges other than the common "unknown firearm" to which Sgt. Ensor attributes the cartridges; (2) Additionally, that Sgt. Ensor only be permitted to state his opinions and bases without any characterization as to degree of certainty (whether "more likely than" not" or "to a reasonable degree of ballistic certainty"); (3) Alternatively, if you disagree with Recommendation No. 2, that Sgt. Ensor only be allowed to express his opinions "more likely than not"; (4) Alternatively, if you disagree with Recommendation Nos. 2 and 3, that Sgt. Ensor only be allowed to express his opinions "to a reasonable degree of ballistic or technical certainty" (or any other version of that standard); Case 1:08-cr-00086-WDQ Document 721 Filed 10/29/2009 Page 57 of 58

the prosecutor or of the examiner not fully prepared for the line of questioning. In other courts, the courts have ruled favourably on the admissibility of firearms-related evidence.¹⁵⁷⁰

In the case of *State of Florida v. Ramirez*,¹⁵⁷¹ a firm decision by the judge rejected the premise of “I know it is a match because I have sufficient background, training and experience”. It sent a clear message to examiners not to just rely on their own subjective opinion, without convincing, logical, scientifically based explanations for the basis of their findings. The court was concerned about the absolute and unequivocal (subjective) certainty with which the examiner testified, without any objective criteria that should have been met. The lack of photographs of the identification increased the concern of the court and it was also found that the methodology lacked the support of meaningful peer review or publication, a prerequisite to scientific acceptance.

In June 2003 in the case of *Her Majesty the Queen v. Baltrusaitis* heard in Ontario, Canada, Judge Thompson ruled that the evidence from a firearm examination that two fired ammunition components as having been cycled through a similar action of the same firearm, without the presence of a firearm, are scientifically reliable if the origination and individuality of the toolmarks can be substantiated. The evidence was admissible in the ruling.¹⁵⁷²

Firearm identification was again challenged in the U.S. Districts Court of the Northern District of Baltimore, Maryland in the case of *U.S. v. Foster and two others*.¹⁵⁷³ Foster and two others were accused of the murder of Vance Beasley on March 21, 2002 and Anthony Walker on January 19, 2002, as both .25 caliber casings from the separate crime scenes matched. In February 2004, three firearm examiners testified in front of Judge Catherine Blake in a *Daubert* hearing on the science of firearm identification. The defence challenged the science of the methodology and called it “pseudo-science”. The court ruled against the defence motion, stating that the science

¹⁵⁷⁰ Serhant JE “The Admissibility of Ballistics in Evidence” 1931 *The Am J Police Sci* 2(3):202-210.

¹⁵⁷¹ *Joseph J. Ramirez v. State of Florida*, Florida Supreme Court Case No. SC92975, December 20, 2001.

¹⁵⁷² *Vytautas (“Chuck”) Baltrusaitis v. Her Majesty the Queen in Right of Ontario et al.* SCC Case Information: 34531, 2012. Also, The Association of Firearm and Toolmark Examiners (AFTE), <https://afte.org/uploads/documents/swggun-queenvbaltrusaitis.pdf> (Date of use: 2 January 2019).

¹⁵⁷³ The Association of Firearm and Toolmark Examiners (AFTE), <https://afte.org/uploads/documents/swggun-usvfoster.pdf> (Date of use: 2 January 2019).

satisfied the *Daubert* requirements. Also in 2004, in a *Frye* motion in the case *State of Florida v. William Flores*,¹⁵⁷⁴ the methodology used to identify markings on a fired shotshell wad to a barrel was challenged by the defence as a new and novel method. Judge Perry ruled that the analytical and quality assurance procedures were not new, but consistent with acceptable scientific testing.

Another comprehensive challenge arose in the case of *United States of America v. Richard Hicks*,¹⁵⁷⁵ heard in the United States Court of Appeals in 2004. Hicks was tried for the murder of officer James Lamance after a high speed chase into an open field. Hicks escaped from the scene without being identified as the shooter by Officer James Lamance's partner, his brother, Officer Kevin Lamance. The cartridge case found at the scene of the shooting was matched to a casing fired from a .30-30 rifle which was found later in Hicks's house. Although Hicks was found not guilty for the capital murder of Officer Lamance in the State Court, the conviction was overturned by the District Court by applying United States Sentencing Guidelines.¹⁵⁷⁶ Hicks argued in his appeal that the ballistics expert, John Beene's cartridge case comparison technique did not meet the criteria for reliability laid down in *Daubert*.

First, he argued that Beene could not state whether: "(1) the technique had ever been empirically tested; (2) the technique had been published in a peer-reviewed article; (3) any studies have been performed to calculate the rate of error for the technique; and (4) whether any standards exist for making shell-casing-to-firearm comparisons".¹⁵⁷⁷ Hicks also noted that Beene had admitted that he had read articles and heard presentations criticising shell casing comparisons precisely because no objective standards or criteria exist for making matches. Moreover, Hicks argued that Beene's application of the casing comparison technique in this case was particularly unreliable because Beene could not remember (even when looking at his notes) how many marks he had used to make the match, how wide or deep the markings had been, and precisely where the marks

¹⁵⁷⁴ *State of Florida v. William Flores*, Case #98-01500, 13th Judicial Court of Florida, November 17, 2004 (Judge Daniel L. Perry).

¹⁵⁷⁵ *United States v. Richard Hicks*, United States Court of Appeals, Fifth Circuit. No. 03-40655, November 2, 2004.

¹⁵⁷⁶ United States Sentencing Guidelines (USSG), 2K2.1(c)(1)(B)'s homicide cross-reference provision, 2004.

¹⁵⁷⁷ *US v. Hicks*, 389 F. 3d 514 - Court of Appeals, 5th Circuit 2004, [524].

had been located on the casings. Additionally, Hicks noted that Beene had admitted that he had not test-fired other .30-30 rifles to exclude markings that were not unique to the rifle found at Hicks's house. Finally, Hicks challenged Beene's qualifications, alleging that Beene was not qualified as an expert to testify that shell casings discovered at the crime scene had been fired from the rifle found at Hicks's home.

Judge King's response to Hicks's arguments was as follows:

"As for Hicks's challenge to Beene's qualifications as a ballistics expert, there was more than ample evidence to permit the district court to find that he is a qualified ballistics expert. This court has held that "[t]o qualify as an expert, 'the witness must have such knowledge or experience in [his] field or calling as to make it appear that his opinion or inference will probably aid the trier in his search for truth.'" *United States v. Bourgeois*, 950 F.2d 980, 987 (5th Cir.1992) (second alteration in original) (quoting *United States v. Johnson*, 575 F.2d 1347, 1361 (5th Cir.1978)). Additionally, Fed.R. Evid. 702 states that an expert may be qualified based on "knowledge, skill, experience, training, or education...." See also *Kumho Tire Co. v. Carmichael*, 526 U.S. at 151, 119 S.Ct. 1167 (discussing witnesses whose expertise is based purely on experience). At the state-court *Daubert* hearing, Beene testified that he had a degree in chemistry, had received training in firearms comparisons testing from the FBI, and had done firearms examinations for over twenty years. At Hicks's trial in federal court, Beene repeated most of these claims, adding that he had performed more than a thousand cartridge-firearm comparisons in the course of his twenty-eight-year career with the Texas Department of Public Safety without a suggestion that any of his matches were incorrect. Based on Beene's training, twenty-eight years of experience, and numerous prior cartridge comparisons, the district court did not abuse its discretion in allowing him to testify as an expert at trial."¹⁵⁷⁸

Judge King also went further and stated that the test of reliability "is flexible". The appeals court upheld the conviction and sentence of the court *a quo*.

In November 2005, in a Massachusetts district court in the case of *U. S. v. Monteiro and five others*,¹⁵⁷⁹ Judge Saris ruled after a six day *Daubert* hearing that the court held that Sgt. Weddleton, the ballistic expert, was sufficiently qualified through training, possessing the necessary experience, and was proficient to testify. However, his proffered testimony was

¹⁵⁷⁸ *US v. Hicks*, 389 F. 3d 514 - Court of Appeals, 5th Circuit 2004, [525].

¹⁵⁷⁹ *United States of America v. Amando Monteiro, Valdir Fernandes, Angelo Brandao, Brima Wurie, Luis Rodrigus, Manuel Lopes, Defendants*. 407 F.Supp.2d 351 (2006).

inadmissible under Rule 702 because he did not follow the established standards in the toolmark identification field with respect to documentation and peer review of his results.¹⁵⁸⁰ Sgt. Weddleton was afforded two weeks to comply with these standards and have his results peer reviewed. Judge Saris furthermore added that:

“Daubert does not require that a party who proffers expert testimony carry the burden of proving to the judge that the expert’s assessment of the situation is correct. As long as an expert’s scientific testimony rests upon “good grounds, based on what is known,” Daubert, 509 U.S. at 590 (internal quotation marks omitted), it should be tested by the adversary process -- competing expert testimony and active cross-examination -- rather than excluded from jurors’ scrutiny for fear that they will not grasp its complexities or satisfactorily weigh its inadequacies. In short, Daubert neither requires nor empowers trial courts to determine which of several competing scientific theories has the best provenance. It demands only that the proponent of the evidence show that the expert’s conclusion has been arrived at in a scientifically sound and methodologically reliable fashion.¹⁵⁸¹

Judge Saris stated that the scientific principles underlying Firearm and Toolmark Identification, specifically that a firearm can leave unique markings on discharged cartridge cases, were reliable. However, she reserved rendering a full opinion as to the reliability of the methodology and protocols used in this particular case.

¹⁵⁸⁰ Moran B “*Photo Documentation of Toolmark Identifications – An Argument in Support*” 2003 *AFTE J* 35:174-181. Although the AFTE guidelines to which Special Agent Curtis referred were not offered into evidence, the Court accepts as credible his testimony that the standard in the field is for the examiner to document his or her findings through the use of notes, sketches, or photographs. Same conclusions. Therefore, the data that we gather should provide a well-defined “roadmap” as to what experiments we performed to answer the question(s) posed, what data was gathered, and a clear demonstration of the evidence from which we supported our conclusion(s). This mechanism of communication among scientists is a substantial part of the process of verification.

¹⁵⁸¹ *United States of America v. Amando Monteiro*, 407 F.Supp.2d 351 (2006) [358].

A number of *Daubert hearings*¹⁵⁸² and *Frye hearings*¹⁵⁸³ were conducted nationally in the United States during the period 2006 to 2010. In none of the cases did the court reject the evidence based on scientific validity and/or reliability, but they did place some restrictions on how the expert may testify.

Another remarkable case in the motion to exclude ballistics testimony, was that of the *State vs. Green*¹⁵⁸⁴ in 2005. Defendants Jonathan Hart and Edward Washington challenged the admissibility of forensic ballistics identification evidence pursuant to *Federal Rules of Evidence 702*. The defendants suggested that the contested conclusion in this case — a match to the exclusion of “every firearm in the world” — is too great a leap from the testimony of O’Shea’s, the forensic examiner. First, they point to the fact that O’Shea was given a single firearm, under circumstances that strongly suggested it was the incriminating weapon, equivalent to an evidentiary show-up, not a line-up.

¹⁵⁸² *Commonwealth of Massachusetts v. Jason Meeks and Michael Warner*, Criminal Action #2002-10961 and #2003-1057, 2006. Also, *U.S. v. Jamaal A. Lewis*, Criminal # U.S. Army 217-08-8512, 2006. Also, *U.S. v. Michael Antonio Natson*, Criminal #4:05-CR-21 (CDL), 2007. Also, *U.S. v. Edgar Diaz, et al* Criminal #CR 05-00167 WHA, 2007. Also, *U.S. v. Khalid Barnes*, Criminal #S9-04-CR. 186, 2008. Also, *State of Washington v. Tony Smith* No. 03-1-00045-7 KNT, 2008. Also, *U.S. v. Damian Brown* Case# 05 CR538, 2008. Also, *State of Ohio v. Eashawn Anderson* Case #CR509503, 2009. Also, *State of Alaska v. Derrick Wren* Case #3AN-03-10649CR, 2009. Also, *People of Michigan v. Doyle Palmer*, Case No. 08-12323, 2009. Also, *State of Ohio v. Demonte Merriweather* Case #514703, 2009. Also, *U.S. v. Marius St. Gerard*, Case # APO AE 09107, 2010. Also, *U.S. v. Ivan Cerna, et al* Case No. CR-08-0730 WHA, 2010.

¹⁵⁸³ *Maryland v. Monti M. Fleming*, Criminal Case #06-46624, 2008. Also, *State of Connecticut v. Robert A. Legnani*, #AC 26840, 2008. Also, *U.S. v. Ronald English*, Criminal #2007 CF1 16618, 2008. Also, *U.S. v. Kevin Edwards* Case #F-516-01, 2008. Also, *Commonwealth of Pennsylvania v. Steven Carl Colegrove* CP-08-CR-0000785-2007, 2009. Also, *U.S. v. Willie Gayden* Criminal Case #2006 CF1-27899, 2009. Also, *U.S. v. Joseph Thomas* #2008 CF1 25845, 2009. Also, *State of New York v. Giovanni Eligio* Indictment No. 4097-08; 2009. Also, *State of Maryland v. Henry Wittingham*, Case # 08-1682X, 2009. Also, *State of Washington v. Daylan Erin Berg and Jeffrey Scott Reed*, Case #09-1-00761-6/Case #09-1-00762-4, 2009. Also, *Maryland V. Monti M. Fleming*, Case # 899, 2010.

¹⁵⁸⁴ *US v. Green*, 405 F. Supp. 2d 104 - Dist. Court, D. Massachusetts 2005 ([...] a “suggestive procedure.”) 432 U.S. 98, 107, 97 S.Ct. 2243, 53 L.Ed.2d 140 (1977). In contrast: In an evidence lineup, the examiner would be presented with multiple specimens, some of which were “foils.” The examiner would, of course, be blind to which items of evidence in the evidence lineup are foils and which the true questioned evidence are. For example, a firearms examiner might be presented with a crime scene bullet and five questioned bullets labeled merely “A” through “E.” Four of those bullets will have been prepared for examination by having been fired through the same make and model as the crime scene bullet and the suspect’s bullet had been. The task of the examiner would then be to choose which, if any, of the questioned bullets were fired through the same weapon as the crime scene bullet had been.

Judge Gertner, in allowing O'Shea to testify, concluded as follows:

“Putting together this precedent with the evidence I have heard, suggests admission but with limitations, limitations identical to those I adopted in Hines. O'Shea is a seasoned observer of firearms and tool marks; he may be able to identify marks that a lay observer would not. But while I will allow O'Shea to testify as to his observations, I will not allow him to conclude that the match he found by dint of the specific methodology he used permits “the exclusion of all other guns” as the source of the shell casings. Defense will be permitted full and fair cross-examination.”¹⁵⁸⁵

In a study performed by Page *et al.*,¹⁵⁸⁶ it was determined that a total of 17.9 % of all analysed *Daubert* challenges on the testimony of forensic firearm examiners, resulted in an exclusion or limitation of the firearm evidence by the court. In the mentioned cases, reliability concerns were mentioned in 52.8 % of the cases. Exclusions and limitations were based on unfounded statistics, error rates and certainties, a lack of good recordkeeping of the analytical scheme followed, deviation from standard operating procedures, and observer bias.¹⁵⁸⁷

The courts were not the only ones challenging firearm and toolmarks evidence. It was also criticised in the NAS report (2009) and PCAST report (2016). The next section will discuss the role of external entities on the use of firearm and toolmarks evidence in forensic investigations.

8.9 External entities and events that influenced the credibility of firearm evidence

8.9.1 The NAS Report

With the report “Strengthening Forensic Science in the United States: A path forward”, published by the National Academics of Science, Engineering, and Medicine in August 2009, certain concerns were raised which had to be addressed by the Firearm and Toolmark community. In the

¹⁵⁸⁵ US v. Green, [124].

¹⁵⁸⁶ Page M *et al.* “Forensic Identification Science Evidence since Daubert: Part I - Quantitative Analysis of the Exclusion of Forensic Identification Science Evidence” 2011 *J Forensic Sci* 56(5):1180-1184.

¹⁵⁸⁷ Page M *et al.* “Forensic Identification Science Evidence Since Daubert: Part II - Judicial Reasoning in Decisions to Exclude Forensic Identification Evidence on Grounds of Reliability” 2011 *J Forensic Sci* 56(4):913-917.

report, the field of firearm analysis was regarded as having little significance beyond law enforcement. The report further indicated that the process still used by courts as admissible evidence, have serious shortcomings in capacity and quality. The authors of the NAS report used a number of selected trial cases to highlight the fact that courts allowed firearm and toolmark evidence based on earlier decisions rather than following *Daubert* rules of evidence.¹⁵⁸⁸

The NAS report acknowledged the scientific interpretation as follows:

“The task of the firearms and toolmark examiner is to identify the individual characteristics of microscopic toolmarks apart from class and subclass characteristics and then to assess the extent of agreement in individual characteristics in the two sets of toolmarks to permit the identification of an individual tool or firearm. Guidance from the Association of Firearm and Tool Mark Examiners (AFTE) indicates that an examiner may offer an opinion that a specific tool or firearm was the source of a specific set of toolmarks or a particular bullet striation pattern when “sufficient agreement” exists in the pattern of two sets of marks. The standards then define agreement as significant “when it exceeds the best agreement demonstrated between tool marks known to have been produced by different tools and is consistent with the agreement demonstrated by tool marks known to have been produced by the same tool.”¹⁵⁸⁹

¹⁵⁸⁸ There is little to indicate that courts review firearms evidence pursuant to *Daubert*’s standard of reliability. See e.g., *United States v. Hicks*, 389 F.3d 514 (5th Cir. 2004) (upholding defendant’s conviction after finding, in part, that it was not an abuse of discretion for the court to admit testimony on shell casing comparisons by the Government’s firearms expert); *United States v. Foster*, 300 F. Supp. 2d 375 (D. Md. 2004) (denying defendant’s motion to exclude expert firearms testimony). Several federal trial judges, however, have subjected expert firearm testimony to rigorous analysis under *Daubert*. In *United States v. Monteiro*, 407 F. Supp. 2d 351 (D. Mass. 2006), Judge Saris concluded that toolmark identification testimony was generally admissible under *Daubert*, but excluded the specific testimony at issue, because the experts failed to properly document their basis for identification, and because an independent examiner had not verified the experts’ conclusions. Likewise, in *United States v. Diaz*, No. 05-CR-167, 2007 WL 485967, at *14 (N.D. Cal. Feb. 12, 2007), Judge Alsup allowed firearm identification testimony under *Daubert*, but prevented experts from testifying to their conclusions “to the exclusion of all other firearms in the world” and only allowed testimony “to a reasonable degree of certainty.” Cf. *United States v. Glynn*, 578 F. Supp. 2d 569 (S.D.N.Y. 2008), where Judge Rakoff precluded testimony that a bullet and shell casings came from a firearm linked to the defendant “to a reasonable degree of ballistics certainty,” because “whatever else ballistics identification analysis could be called, it could not fairly be called ‘science.’” However, the judge ruled that although inadmissible under *Daubert*, testimony that the evidence was “more likely than not” from the firearm was admissible under Federal Rule of Evidence 401. See also Green, 405 F. Supp. 2d 104.

¹⁵⁸⁹ Theory of identification, range of striae comparison reports and modified glossary definitions—An AFTE Criteria for Identification Committee report. 1992 *AFTE J* 24:336-340.

The report however mentioned that the fundamental assumptions of uniqueness and reproducibility of toolmarks have not been fully demonstrated. It was recommended that a significant amount of research was needed to scientifically determine the degree to which firearm-related toolmarks are unique or even to quantitatively characterise the probability of uniqueness.¹⁵⁹⁰ It also highlighted the basis of all forensic identification as probability theory, and that examiners hence cannot assert a conclusion of an “*identification to exclusion of all others in the world, but at best can only assert a very small (objective or subjective) probability of a coincidental match.*”¹⁵⁹¹ (emphasis added)

The SWGGUN responded to the criticism in the 2009 report, stating that:

“The SWGGUN has been aware of the scientific and systemic issues identified in this report for some time and has been working diligently to address them. . . . [the NRC report] identifies the areas where we must fundamentally improve our procedures to enhance the quality and reliability of our scientific results, as well as better articulate the basis of our science.”¹⁵⁹²

Soon after the NAS report release, many defence counsel in various U.S. states started to use the report for motion of dismissal of firearms evidence on Rule 702 hearings, *Daubert* hearings, or Porter hearings.¹⁵⁹³ In all of the cases the motions were denied and forensic firearm evidence was still considered reliable despite the allegations made in the NAS report.

Other researchers published papers following the NAS report. Saks¹⁵⁹⁴ described three research strategies that would improve firearm identification sciences. He recommended a DNA model, a black box model, and basic research models. The DNA model would focus on building databases

¹⁵⁹⁰ All quotes from the National Research Council. 2008. *Ballistic Imaging*. Washington, DC: The National Academies Press, [3].

¹⁵⁹¹ The National Research Council “Ballistic Imaging” *NRC Washington DC 2008* [3, 82, 20].

¹⁵⁹² Scientific Working Group on Firearms and Toolmarks. Response to NAS Report, 2009.

¹⁵⁹³ *State of Montana v. Patrick O. Neiss*, Case #DC 14-0627, Montana Thirteenth Judicial District Court; *State of Connecticut v. Donald Raynor*, Case #HHD-CR13-0667367-T, Superior Court of Hartford; *State of Florida v. Bobby Mellad*, Case No. 09-16048-CF10A, Circuit Court of Broward County; *State of Colorado v. James Eagan Holmes*, Case No. 12CR1522, District Court of Arapahoe County.

¹⁵⁹⁴ Saks MJ “Forensic identification: From a faith-based ‘Science’ to a scientific science” 2010 *Forensic Sci Int* 201:14-17.

to assess the variation of attributes in a reference population, allowing examiners to determine a probability of an incidental match. The black box model will still follow a subjective approach, but with higher accuracies in reporting results. Basic research models will assess the frequencies of consecutive matching striae in pairs of projectiles that are known matches versus known non-matches. Other researchers are of the opinion that between the three models, the error rate of a minimum number of consecutive matching striae can be stated.¹⁵⁹⁵

8.9.2 OSAC Sub-committee on pattern evidence

In 2013, the U.S. federal government decided to defund all standard working groups and all functions were incorporated into the NIST/DOJ Organization of Scientific Area Committees (OSAC). Although supporting the OSAC initiative, the AFTE Board of Directors decided to republish and maintain the ARK on the AFTE website.¹⁵⁹⁶ The OSAC sub-committee consists of a combination of practitioners (local, state and federal laboratories) and researchers from academia. From the start, the Forensic Science Standards Board (FSSB) provided the opportunity for OSAC sub-committees to identify a number of baseline documents and reference materials to reflect the current state of best practices in each discipline. The committee identified a number of documents that fell under the auspice of SWGGUN.¹⁵⁹⁷

The committee also constructed a number of documents that are in the process of becoming ASTM standards, as discussed in the chapters dealing with other disciplines in this thesis. These standards consist of guidelines on examination, training/education and reporting, standards for 2D and 3D comparisons, and range of conclusions and criteria in examinations.¹⁵⁹⁸ To date, no approved documents on firearm and toolmarks are listed on the OSAC registry.

¹⁵⁹⁵ Biasotti A *et al.* "Firearms and toolmark identification" In: Faigman DL, Saks MJ, Sanders J and Cheng EK eds *Modern Scientific Evidence: The Law and Science of Expert Testimony* (4 ed St. Paul, MN: Thomson-West 2010) 645-723.

¹⁵⁹⁶ The Association of Firearm and Tool Mark Examiners <https://afte.org/resources/swggun-ark> (Date of use: 9 January 2019).

¹⁵⁹⁷ Organization of Scientific Area Committees (OSAC) Firearms and Toolmarks Subcommittee "Discipline-Specific Baseline Documents" <https://www.nist.gov/topics/forensic-science/firearms-toolmarks-subcommittee> (Date of use: 26 November 2019).

¹⁵⁹⁸ OSAC "Documents in Process" <https://www.nist.gov/topics/forensic-science/firearms-toolmarks-subcommittee> (Date of use: 26 November 2019).

8.9.3 PCAST

In contrast to the NAS report, the PCAST report¹⁵⁹⁹ primarily focuses on feature comparison methods. As discussed in earlier chapters, the PCAST committee focuses on foundational validity, where the method has been subjected to empirical testing within a larger science community (testing repeatability and reproducibility, and providing valid estimates on method accuracy), and individual steps that must be evaluated as if it were a “black box” study. The PCAST committee stated that with the lack of estimates on accuracy, statements made by examiners that two samples are similar or indistinguishable are scientifically meaningless (i.e., without any probative value).

The committee also concurred with the NAS report that many of the earlier studies were “inappropriately” designed to assess foundational validity and estimate reliability. The committee also argued that the earlier studies had underestimated the false positive rate by at least 100-fold. The committee held that the designed studies had serious flaws, e.g. that they entailed internal dependencies that constrained examiners’ answers and allowed examiners to make inferences about the study design.

The PCAST committee, however, acknowledged one research advance since the 2009 NAS report, which was the “black box” study that had been conducted by an independent testing laboratory (Ames Laboratory). In that study, the false positive rate was estimated at 1 in 66, with a confidence bound indicating that the rate could be as high as 1 in 46. The study was never published in any scientific journal. It is ironical that the same committee who refused to rely on research articles if they were not published in peer-reviewed journals, used this unpublished work as a reference to emphasise high error rates in firearm examinations. The committee also mentioned that to prove foundational validity, more such studies, ideally published in peer-reviewed scientific literature, would be required. The committee unfortunately did not acknowledge the AFTE

¹⁵⁹⁹ PCAST *Report* 2016.

journal as a peer-reviewed scientific journal, due to its restricted access to members of the larger scientific community.

The PCAST committee made some recommendations, some of which are pertinent for this study:

- Experts testifying on firearm examinations should complete rigorous proficiency testing on a large number of test problems to determine their competency on accuracy; and those results should be disclosed. It should also be disclosed whether the proficiency test was a blind proficiency or part of a proficiency scheme, such as CTS.
- Firearm examination should follow paths of a more subjective approach, which would require more “black box” studies to assess the scientific validity and reliability.
- The need for the development and testing of image-analysis algorithms for comparing similarity of tool marks on cartridge cases and projectiles was emphasised. The lack of large open access databases was however a concern for the development and validation of initial proposals. The NIST and the FBI were acknowledged as the entities that should take the lead the development of such large datasets.¹⁶⁰⁰

The PCAST committee, however, only relied on a selected number of research studies to formulate the false positive rates in those studies. The committee did not use studies where no false positives were reported. Table 8.2 is an extract from the PCAST report finding on false positive rates.

¹⁶⁰⁰ PCAST Report 2016 1[1-12].

Table 8.2 False positive rates as per PCAST Report¹⁶⁰¹

Study Type	Results for different-source comparisons				
	Raw Data	Inconclusives	False positives among conclusive exams		
	Exclusions/ Inconclusives/ False positives		Freq. (Confidence Bound	Estimate d Rate	Bound on Rate
Set-to-set/closed (four studies)	10,205/23/2	0.2%	0.02% (0.06%)	1 in 5103	1 in 1612
Set-to-set/partly open (Miami-Dade study)	188/138/4	41.8%	2.0% (4.7%)	1 in 49	1 in 21
Black-box study (Ames Laboratory study)	1421/735/22	33.7%	1.5% (2.2%)	1 in 66	1 in 46

The committee did not directly address human factors in firearm and toolmark examinations, but mentioned that similar pathways should be followed as discussed in fingerprint examinations in section 7.6.4 of Chapter 7 of this thesis.

The AFTE responded¹⁶⁰² to the PCAST report, acknowledging the challenges the committee had faced in order to understand the scientific field of comparative sciences from their “brief” review of the literature. The AFTE also agreed to the improvements needed in structured research that would strengthen the foundational and applied validity of firearm identification. They also agreed that more should be done to reduce cognitive bias and improve the transition to subjectivity. However, the AFTE was disappointed in PCAST’s choice not to acknowledge all the relevant research conducted in the field over the years. They believed decades of studies have demonstrated validation and proficiency within firearm and toolmark examinations, providing a

¹⁶⁰¹ PCAST Report 2016 [11].

¹⁶⁰² AFTE “Response to PCAST Report on Forensic Science” 2016-10-31. <https://afte.org/resources/afte-position-documents> (Date of use: 26 November 2019).

solid scientific foundation, competent examiners employing standards, validated procedures, and limited false identifications.

The AFTE statement also criticised the PCAST committee's lack of insight to only consider "black box" studies as valuable research, overseeing the quality of multiple research efforts that contributed to the science. In their response, they argued that greater emphasis should have been placed on the performance of the individual examiner through proficiency testing, rather than focusing on a single "black box" study.

Finally, the AFTE criticised the statement made that the field required an independent inquiry into validation studies and peer-reviewed literature. The AFTE maintained that other disciplines, such as those of fingerprints and DNA, have a larger invested interest from a greater science community, whereas firearm identification is limited to a few profit-making applications and does not attract research attention from the private sector.¹⁶⁰³

The OSAC sub-committee also responded¹⁶⁰⁴ to the PCAST report with a more detailed report, which included a call for additional references to review. The OSAC committee disagreed on a number of statements made by the PCAST report. They found that the conclusion made by PCAST that: "[...] firearms analysis currently falls short of the criteria for foundational validity, because there is only a single appropriately designed study to measure validity and estimate reliability", is inaccurate and criticised their lack of insight to acknowledge all relevant validation studies. The OSAC report added additional references on validation studies that were overlooked or ignored by the PCAST revision. The OSAC committee response also highlighted the calculated mistakes¹⁶⁰⁵ made by PCAST when they determined error rates as stipulated in Table 8.2 above. They highlighted the studies of Baldwin *et al.*, Brundage, Hamby and Fadul, discussed earlier in

¹⁶⁰³ AFTE Response to PCAST Report 2016.

¹⁶⁰⁴ Organization of Scientific Area Committees (OSAC) Firearms and Toolmarks Sub-committee "Response to the President's Council of Advisors on Science and Technology (PCAST) Call for Additional References Regarding its Report Forensic Science in Criminal Courts: Ensuring Scientific Validity of Feature-Comparison Methods", 14 December 2016.

¹⁶⁰⁵ OSAC Firearms and Toolmarks Subcommittee's Response to the PCAST Call for Additional References, Appendix A, [11-13], 14 December 2016.

this chapter, to provide a more correct reflection on error rates within firearm identification. The OSAC committee also disagreed on how PCAST evaluated within set studies from Smith and DeFrance, and set-to-set comparison/close set studies from Stroman, Brundage, Fadul, and Hamby, discussed earlier in this chapter.

The OSAC sub-committee also accused PCAST of discounting eight of the nine validation studies they reviewed, with two of those studies having no false positive results. The committee argued that the selective use of studies with higher error rates and ignoring studies with low error rates, made the PCAST committee appear biased and unbelievable.

The OSAC sub-committee also disagreed with the statement by PCAST that: “methods consisting of procedures that are each defined with enough standardized and quantifiable detail that they can be performed by either an automated system or human examiners exercising little or no judgment”,¹⁶⁰⁶ as every forensic discipline requires some human interaction or human judgment during examination and interpretation of results. However, the committee agreed to support continuous efforts through research for more objective analytical methods.

8.10 Future developments with regard to firearm and toolmark evidence

Firearm and toolmark evidence are very prominent forensic evidence used frequently within the criminal justice system. In this chapter, a number of challenges, successes, and failures have been discussed. Although the discipline overcame many challenges, not all questions about its validity have been answered. The following key aspects should be mentioned for future enhancement to strengthen the discipline, based on past experiences, each discussed in more detail further below:

- Number of test fires needed for comparison
- Implementation of 3D automated comparison systems
- Continuation of structured research to support foundational validity
- Structured blind proficiency testing
- An understanding of statistical foundation of firearm examination among examiners

¹⁶⁰⁶ PCAST Report 2016 Section 4.1 [46-47].

- An understanding of basic foundational principles on firearm examination among legal professionals and jury members.

8.10.1 *Number of test fires required*

Although a set recommended number of test fires has been provided by the ATF (e.g two test fires), justification for this number has never been challenged. Some research papers, discussed in section 7.3.3 of this chapter, indicate that higher numbers are necessary to make any meaningful statistical inferences. Crime laboratories follow the ATF standard, as it is also a cost saving approach, considering that more test fires will have a cost implication (requiring the purchase of more ammunition). However, cost should never receive preference over quality, and a statistical justification should be explored through further research. Law *et al.*¹⁶⁰⁷ made valid points in their suggested research conclusion. The authors suggested two additional research topics that need to be explored in order to get a better understanding of the number of test fires needed, namely the:

- Determination of the most appropriate bounds for equivalence in both distribution location and dispersion, and
- Calculation of likelihood ratios.

This will allow for a more statistical understanding of inter-variability between test-fires, before comparisons are made with the crime scene samples. Once the examiners know where these variabilities are coming from between test fires, it could explain the absence of markings on crime scene evidence.

8.10.2 *Implementation of 3D automated comparison system*

A number of methods to measure surface topography have been discussed.¹⁶⁰⁸ They are classified into three categories – line profiling, area integrating, and areal topography. They are well

¹⁶⁰⁷ Law EF “Determining the number of test fires” 2018 [56-61].

¹⁶⁰⁸ Vorburger *et al.* “Topography measurements and applications in ballistics and tool mark identifications” 2016 *PMC 12. Surf Topogr 4(1):013002.*

described in ISO 25178-6.¹⁶⁰⁹ In 3D technology, the topography features of projectiles and cartridge cases are in the micrometer-to-millimeter lateral range with heights in the sub micrometer-to-hundred micrometer range. Commercial instruments, especially with optical capability, are available to capture images in this narrow range. The most currently used instrument in firearm and toolmark laboratories is confocal microscopy when used in reflection mode.¹⁶¹⁰ The instrument allows for the detection of variations in surface height and topography when the surface is virtually scanned along the optical axis of the microscope. A topography image of the breechface impression, firing pin and aperture shear shows remarkable detail for examiners to visualise during examinations. Conventional 2D optical images are largely affected by lighting conditions (light source, lighting direction, intensity, colour, and reflectivity of the material), whereas 3D technology overcomes those limitations. Another optical instrument is coherence scanning interferometry (CSI).¹⁶¹¹ It is not as popular as confocal microscopy, but the microscope can be moved vertically to observe a maximum in the signal modulation in order to locate the height of a surface point relative to its neighboring points. It is in a way similar to confocal microscopy. Both confocal microscopy and CSI provide high resolution images, which require long scanning times and form part of the reasons why this methodology has not been fully adopted in more crime laboratories.¹⁶¹²

Two other topographical measurements that had been researched is focus variation and photometric stereo. Focus variation locates the surface at its sharpest, best focused positions during scans and can measure sloped surfaces up to nearly 90 degrees. Individual pixels of peaks and valleys are averaged to provide height sensitivity, which involves a collective response from neighboring pixels.¹⁶¹³ Photometric stereo (shape from shading) involves the decoding of illumination patterns on surfaces. In some cases a soft transparent gel (GelSight), is placed over

¹⁶⁰⁹ International Organization for Standardization “Geometrical product specifications (GPS) — Surface texture: Areal — Part 6: Classification of methods for measuring surface texture”, ISO 25178-6:2010.

¹⁶¹⁰ ISO “Geometrical product specifications (GPS) — Surface texture: Areal — Part 607: Nominal characteristics of non-contact (confocal microscopy) instruments” ISO 25178-607:2019.

¹⁶¹¹ ISO “Geometrical product specifications (GPS) — Surface texture: Areal — Part 604: Nominal characteristics of non-contact (coherence scanning interferometry) instruments” ISO 25178-604:2013.

¹⁶¹² Monturo *Firearm Examination* 2019 [277].

¹⁶¹³ Helmlí F *Focus variation instruments* (Optical measurement of surface topography, Chapter 7, Springer-Verlag Berlin 2011).

the surface to minimise the effects of non-uniform surface reflectance properties such as specularities. Six light sources evenly spaced azimuthally illuminate the surface in turn at a grazing angle. The patterns are analysed and a 3D surface topography image is produced.¹⁶¹⁴

The field of imaging is constantly evolving and databases using confocal microscopy imaging are currently developed by NIST for future use by crime laboratories to assist in casework analysis. Once established, it will be a more reliable source for comparison than the traditional 2D approaches currently in practice.

8.10.3 *Structured research*

Academia plays an integral part in forensic science development and research. The lack of access to AFTE journals by the larger scientific community restricts future researchers to assist in the scientific development of the firearm and toolmark discipline. The AFTE expected NAS and PCAST to acknowledge the research that was performed within the discipline, but does not allow the larger science community access to open source journals. Although the comparative methodology is meant for the trained eye, research progress regarding its physical, statistical and interpretational concepts that are generic in the larger science community is negatively inhibited.

A number of published papers in the AFTE Journal would have had greater value if the authors had a better understanding of research methods and statistical inferences associated with the data retrieved. Since the NAS report and the PCAST report, remarkable progress has been observed with actual empirical values that contribute to the scientific foundation of the evidence, and complies with the Daubert requirements.

Under control of the Department of Justice, entities such as the NIST, CSAFE and other academic contributors, crime laboratories should be more open to collaborative research efforts with their case samples and data images from completed cases. Practitioners will learn more on statistical methodology and practices, and in return, researchers will have a better understanding of the

¹⁶¹⁴ Johnson MK *et al.* "Microgeometry capture using an elastomeric sensor" 2011 *ACM Trans Graph* 30:46.

challenges practitioners are facing with real casework samples. Mutual research efforts will strengthen the discipline of firearm and toolmark examination.

8.10.4 *Proficiency testing*

Well-structured proficiency testing is lacking in the field of firearm examination. Research studies have shown some variability on projectiles and cartridge casing discharged from the same firearm. Traditionally, proficiency testing was based on the concept of discharging ammunition from the same firearm and sending it to various laboratories for same source identification. However, it did not take in account the variabilities and transfer damages associated with the processes. What might have been an easy comparison for one examiner because of good quality markings, could have been more challenging for the next examiner due to quality changes during transit.

In recent years, processes such as replica moulding (a process where a discharged projectile or cartridge can be replicated in a resin mould) helped to overcome variances during comparisons. It enables proficiency test providers to distribute a replicate sample from a single discharged projectile or cartridge to multiple examiners with the expectancy to receive similar answers with the same difficult level.¹⁶¹⁵

More recently, with the development of measured 3D surface topography, analysis can now be performed on the computer without physical access to the original working evidence. Sample images are captured on a central place and the images distributed nationally or internationally, a process called virtual comparison microscopy (VCM). This technology allows for instant access to remote or historic data, without transferring the physical evidence to the laboratory. Digital files of the original evidence can be transferred without the possibility of transfer damages. The technology also has advantages in training, validation studies, and proficiency testing. It allows for easy distribution of information sharing between examiners internationally, and faster turnaround on proficiency testing results.

¹⁶¹⁵ Pauw-Vugts “FAID2009: Proficiency test and workshop” 2013.

A centralised entity can host an open source library for examiners to download example files when unique or challenged samples are received. It can also contribute to sub-class characteristic data acquisition. This technology can also assist in the improvement of laboratory efficiency of verifications and blind verifications. Cross laboratory verifications can be conducted and true blind verification can be completed by hiding all information from the first examiner's analysis from the verifier.

Duez *et al.*¹⁶¹⁶ validated the use of the VCM in firearm examination when they included 46 trained examiners in a study after collecting a number of 3D surface topographies on a Cadre TopMatch 3D scanning system. Each examiner received two test sets with three knowns and four unknowns. They had to indicate the regions of similarity and differences and all 46 examiners (368 tests) were correct in their findings.

8.10.5 *Understanding of statistical approaches by examiners*

The methodology to establish whether two projectiles or cartridge cases were discharged by the same firearm requires some assessment of similarity between the working objects. The examiner wants to derive a quantitative measure of geometric similarity that would establish identification or exclusion of the working objects discharged from the same firearm. Traditionally, this was accomplished through comparison work performed by the "trained" examiner, using his/her judgment in a way that is difficult to quantify. "Trained" is emphasised here, because not even standardised training is well quantified within the field of firearm and toolmark examination. Although the AFTE has a certification program, a relative small percentage of examiners working in crime laboratories are certified internationally. The majority of crime laboratories have internal training modules to train examiners. Historically, examiners were hired based on their interest in firearms and a good eye for detail. With the lack of scientific and statistical foundations, the majority of firearm examiners found it hard to grasp the concept of foundational validity during testimony. The general over reliance on the lack of knowledge by legal professionals kept the discipline afloat during the last century, but as the gap is closing, examiners will need to enhance their knowledge

¹⁶¹⁶ Duez P *et al.* "Development and validation of a virtual examination tool for firearm forensics" 2018 *J Forensic Sci* 63(4):1069-1084.

and understanding of surface topography and importance of similarity as a surface property in this field. Merely showing images which display similarities in the courtroom will soon be not enough for the acceptance of the evidence as admissible by courts. Automated systems with their associated algorithmic and parametric findings on individualised characteristics on topographic surfaces, as well as the quantitative value in similarity, will need to be explained scientifically. Management in crime laboratories should acknowledge scientific enhancements in this field and prepare practitioners accordingly.

Recent developments on topography measuring instruments in the field requires a better understanding of statistics and the value of evidence presented to court. As databases grow, scoring functions should address two main comparison tasks:

- a sorting function which accepts a single reference surface and a set of candidate surfaces, which sorts the candidate set to rank the surface scans from most to least similar as compared to the reference, and
- a scoring function that, given two surfaces, computes a statistically meaningful quantified measure of comparison.¹⁶¹⁷

The quantified statistical comparison through topography measuring instruments should be in a form of a likelihood ratio, odds ratio, or an absolute probability and not just a ranking. Monturo¹⁶¹⁸ describes how preprocessing (a required step before surface comparison), cross correlation function (CCF), advanced similarity methods, and statistical error rate estimations will shape the future of more sophisticated comparison approaches.

It would be important for examiners and internal training coordinators to incorporate new developments in the field of firearm examination. A statistical foundation should also be embedded in examiners when inferences are made on forensic evidence.

¹⁶¹⁷ Monturo *firearm examination* 2019 [283-284].

¹⁶¹⁸ Monturo *firearm examination* 2019 [284-296].

8.10.6 *Understanding of basic principles of firearm examination by legal professionals*

In an adversarial legal system, legal representatives need to understand the basic concepts of the evidence they will be presenting or question. Only when the scientific discussion becomes too technical, the prosecution will need a private expert to explain that technicality. The lack of basic scientific knowledge of any forensic evidence can cause defence counsel to focus on other concepts, such as chain of evidence or the experience of the examiner. This practice has unfortunately left the science behind the evidence unchallenged for many decades.

Efforts made by the West Virginia University Law School, in collaboration with their Forensic Department, to create an L.L.M. in forensic science, were met with a lack of interest from legal professionals and was subsequently placed on hold after three years. Besides these efforts, other programs on regional and state levels offer annual one- or two-day courses with the aim to educate legal professionals on forensic science. If it takes two years of foundational STEM courses for scientists to become forensic scientists, a two-day course will provide little or no benefit to any legal professional in the criminal justice system. Justice departments should audit the current state of affairs within the justice system and decide on a standardised minimum requirement of training for legal professionals practicing in criminal proceedings. There are a select few jurisdictions that understand the need for and have established forensic commissions, such as the Texas Forensic Science Commission, consisting of Judges, prosecuting and defence attorneys, forensic scientists and academics that promote training and developments in all the entities within the criminal justice system.

Understanding the basic terminology and methodology in firearm examination will assist in the formulation of better legal arguments in the courtroom and test the science and those testifying about it more efficiently. It will provide justification for an adversarial system and not just a one sided presentation of evidence. The scientific value should be clearly understood by juries to make informed decisions about the evidence.

8.11 Conclusion

The claim of firearm examination as non-scientific or a pseudo-science is a contested one. Similar to fingerprint examination, the validity of the pattern evidence had been established for many years. The developments on optics allowed for a better understanding of surface topography in the field, and provided higher confidence among examiners. As more studies are being published on the validity of 3D automated systems and the use of confocal microscopy, and other imaging technologies, the migration will increase, facing out the traditional 2D systems.

Although many challenges in the field relate to subjective observational methodology, a demand for objective methods of identification (referring to known error rates and statistical reliability), started receiving more attention in the last decade. The focus has turned to the creation of statistical algorithmic capability on comparing toolmarks to determine statistical similarity, and in the process, develop an ability to separate matching and nonmatching toolmarks.

Research efforts were also assigned to the determination of the origin of the variability and to quantify the variability in a statistical manner. A number of variabilities occur because of chemical and mechanical processes when a firearm is discharged. Other contributors to variability are the amount/type of propellant, composition of primer and type of ammunition.

Ultimately, the end goal is to assess the random match probability that will indicate the strength of the toolmark evidence for the court to make reasonable conclusions. Although DNA has already accomplished this step, it is more challenging for toolmark evidence to reach the same statistical concepts. The nature and distribution of the evidence are different from DNA, and similar assumptions cannot be made within toolmark examinations.

Continuous efforts from NIST, CSAFE and other role-players, and funding support from NIJ, will continue to strengthen the field of firearm and toolmark examinations.

Chapter 9 Conclusion and recommendations

The relationship between law and science is conventionally viewed as complex and reflexive. However, despite the challenges (some of which were alluded to in this thesis), the relationship currently is stronger than ever before. Efforts of organisations such as AAFS, OSAC, forensic science commissions, to name a few, have added incalculable value to the vast amount of scientific knowledge in the field of forensic science disciplines, and specifically the scientific validity of methods discussed in chapters 5, 6, 7 and 8 of this thesis. Regardless of whether adversarial or inquisitorial legal systems, the science was tested, debated and accepted with some exceptions. Scientific methodology and admissibility requirements changed over the last decade and many examples exist of acceptable transitions in the criminal justice system.

The aim of this thesis was to evaluate the current state of forensic science knowledge and its integration into legal systems. This final chapter will draw on the conclusions and recommendations made in the preceding chapters, starting with the availability and accessibility of scientific knowledge and problems associated with these. Secondly, developments within the forensic science disciplines and future research opportunities to close current gaps will be canvassed. Thirdly, the establishment of entities that will provide better operational structures to forensic science laboratories and crime scene units will be discussed. In the final instance, the chapter will turn to the structures that will support better communication and training within both entities of law and science.

9.1 Scientific knowledge and its accessibility

Forensic science knowledge has been published in scholarly books and journals as early as the 17th century, whilst older papers have been preserved and archived in designated libraries. Many of these papers have since been digitalised and are accessible electronically or may be requested for review from selected libraries. In the 20th century, scientific publications found their way into different scientific journals, depending on the area of interest. For example, papers related to fingerprint development and examination will traditionally be published in the *Journal of International Association of Identification*, whereas firearm and toolmark papers will be submitted to the *AFTE* journal. The majority of contemporary journals rely on membership subscription with

associated fees. It is almost impossible for crime laboratory directors to subscribe to all scientific journals internationally and their access to the latest developments are limited to those that they are subscribed to. In order to address this gap, Interpol Symposiums¹⁶¹⁹ regularly highlights the majority of publications per forensic discipline, a practice that has started in the 1990s. A second problem in crime laboratories is the lack of time allowed to explore and read scientific publications. Scientists traditionally face huge backlogs and ever-increasing turnaround times for forensic evidence. One consequence of this fast-paced environment is that they do not keep up with new developments in their field, unless if new policies and procedures force them to change. This constant knee-jerk or reactive catching-up process is harmful to the profession in general. Thirdly, legal professionals generally have little to no access to forensic science knowledge and are not able to educate themselves on scientific developments other than relying on forensic practitioners, reading forensic files or law reviews containing scant scientific knowledge.

The thesis makes the following recommendations to remedy the above shortcoming:

- a) Forensic scientific literature should be available to the larger scientific community for review. It can be accomplished through establishing a centralised literature hub that allows for paid access to selected publications. A notification e-mail program similar to that of ResearchGate or Academia would be helpful for scientists, legal professionals or researchers, to receive notifications on papers published on discipline specific topics.
- b) Laboratory managers or supervisors should provide adequate time for frequent academic discussions on new scientific papers at the workplace. When a publication of interest is identified, an open forum should be implemented and the content of the article discussed and debated. It will allow for experts to stay current on new research and developments in their respective disciplines. In terms of ISO17025:2017 (Accreditation standard for calibration and testing laboratories), laboratory managers are responsible for the accessibility of literature for the continuous development of practitioners. They should create a culture of

¹⁶¹⁹ 14th, 15th, 16th, 17th, and 18th International Forensic Science Symposiums, Interpol, 1993 to 2016.

continuous learning in the workplace, with the emphasis on enhancement of scientific knowledge.

- c) Develop an outreach program for legal professionals for the sharing of scientific knowledge. There is a perception that the less legal professionals know, the less questions they may ask during examination and cross-examination of testimony. Just as scientists need to learn how to argue scientific knowledge, legal professionals need to have a clear understanding of what constitutes scientific validity.

9.2 Improvements within forensic science

The scientific foundation of the majority of disciplines within the forensic science profession was the focus of relevant chapters in this thesis. This scientific recognition was a gradual process. Saks and Koehler¹⁶²⁰ describe the paradigm shift in forensic science from a model of improvised law enforcement practices learnt through on-the-job apprenticeship, to a more rigorous methodology rooted in scientific principles. These methods now incorporate empirical data and statistics.

9.2.1 Controlled substances

[9.2.1.1 Regulation of substances](#)

The legal regulation of controlled substances is based on two objectives, namely, (1) the protection of persons from the exposure of harmful substances of abuse in an uncontrolled market, and (2) direction to forensic drug chemists on which substances are regulated within a specific jurisdiction. The discipline evolved to answer questions involving chemical compounds, products, or process identification. Scientific developments gradually began to solve cases that could only be explained or resolved when analytical methods of investigation and instrumentation with chemistry as the

¹⁶²⁰ Saks MJ and Koehler JJ "The coming paradigm shift in forensic identification science" 2005 *Science* 309:892-895.

main core were applied. The formulation of the legislation and exact wording used in legislation have always played a significant role in drug analysis and the reporting of controlled substances. Early regulations were occupied with the identification of naturally or semi-naturally occurring substances, such as opiates, coca plants, and marijuana, which were misused by the community. The number of substances that were regulated increased over time as more substances were misused, causing dangerous depending physical and psychological effects on individuals.

Early discoveries in the identification of controlled substances were made possible through colour tests, measuring boiling and melting points, ultra-violet absorption spectra, and infrared absorption spectra.¹⁶²¹ As clandestine chemists became more knowledgeable on organic chemical synthesis, the list of controlled substances increased. The increase in illicit substances required rapid and effective action, as well as ingenuity on the part of forensic scientists. The increase in the number of new drugs led to more substance control regulations which placed additional pressure on forensic scientists internationally to use faster, more accurate, and more specific methods of identification and analysis. The legal regulation of controlled substances over the past century is characterised by a recurring cycle consisting of the following steps:

- a naturally occurring or synthesised substance with either a psychological or physical dependence or both would be abused; to protect society from the dangers of that substance;
- laws would then be drafted and enacted;
- forensic scientists would develop a methodology that would enable them to structurally identify those substances; and
- clandestine operators would monitor the structural identity of controlled substances within those Acts and then synthesise similar substances that would mimic and/or enhance effects of those listed substances.

The process will repeat itself unless a change in regulations breaks the “catching-up” cycle.

¹⁶²¹ Bureau of Drug Abuse Control, 1967.

https://erowid.org/library/periodicals/microgram/microgram_1967_11_v01n01.pdf (Date of use: 31 January 2019).

The thesis makes the following recommendation in this regard:

Legislation should be drafted in such way that criminal sanctions will apply to any person producing a substance knowing that it will alter or act as a drug that is harmful for human consumption, unless it is properly researched through clinical trials and approved by health regulating authorities such as the FDA. First attempts in that direction have already been taken in Ohio and Texas with the enactment of a Pharmacophore Act that will ultimately prohibit the synthesis of designer drugs.¹⁶²² Such substances have to be tested for differences in both pharmacological and toxicological effects to ensure safety before approval. Forensic drug chemists should not be concerned about pharmacokinetics, as their role will only be to identify a chemical structure of the unknown substance. If a base structure can be derived from the chemical structure, it will be falling within the pharmacophore regulated schedules.

9.2.1.2 Balance between results needed and cost of analytical scheme

The scientific knowledge is further enhanced with research papers on sophisticated instrumentation used to distinguish between close structurally related substances and substances with low quantities (such as Fentanyl). These instruments, such as triple quadrupole spectrometers, are very costly and maintenance costs make it inaccessible for underfunded laboratories to obtain. The majority of unknown samples do not require analysis on such instruments and less specific and sensitive instruments would be sufficient for use in those cases.

The thesis makes the following recommendation to address this shortcoming:

The scientific result needed should not be exceeded by using an overly expensive analytical scheme. For example, one would not analyse cocaine with a UPLC/MSMS if a GC/MS will provide the same result. When a laboratory receives an unknown sample, which cannot be

¹⁶²² Carle "Chemistry of clandestine drugs" 2016.

identified with a routinely used analytical scheme, samples should be send to a better equipped accredited laboratory in the same state for analysis or to the DEA laboratory.

9.2.1.3 Value of drug courts

The United States set the example with the establishment of drug courts, with other jurisdictions following suit with similar models, with equal success. The United Kingdom's Ministry of Justice introduced dedicated drug courts in England and Wales in 2004, and in 2011 conducted a pilot evaluation process study to determine the successes of such systems in the United Kingdom.¹⁶²³ Successes detailed in their report include speedy trials, better rehabilitation programs, and less crime in those communities. There are currently over 1,200 counties in the United States with dedicated drug courts.¹⁶²⁴ The main benefit for forensic experts and legal professionals is that the more analytical the data presented over time in court is, the better the understanding of the science by legal professionals. When various experts testify in the same court, judges as "gatekeepers" will be able to identify aspects of similarity, understatements, and overstatements of evidence presented.

The thesis makes the following recommendation in this regard:

Legal professionals should be cautioned not to get too accustomed to presiding testimony on a specific issue, as the scientific field continuously develops with new technology and improved recommended standards. Refresher training programs should be offered to legal professionals within those dedicated systems to ensure continuous success and common understanding. Peer-reviewed journals focusing on new legislation and new developments in scientific methodology that serve both professions would be ideal.

¹⁶²³ Kerr "Dedicated drug courts" 2011.

¹⁶²⁴ Holst "Twenty Years of Drug Courts" 2010.

9.2.1.4 Research opportunities

Forensic drug chemistry is setting the tone in forensic science, as may be gleaned from the little criticism expressed in the NAS and PCAST reports. Both committees applaud the discipline for the sound scientific foundations of the field. Although not without challenges and failures, it is recognised as a mature forensic science discipline and one of the areas with a strong scientific underpinning. The gap between the law and the science in forensic drug chemistry is marginally smaller than those in other disciplines in the forensic community. The scientific methodology, if applied correctly, is valid, reliable, and repeatable. With the increase in the development of designer drugs, limitations will surface more frequently and new approaches on interpretation of spectra should be researched continuously. Data exists in crime laboratories to determine qualitative error rates and should be published more widely to strengthen the discipline. Research should also focus on mobility of analytical instruments for on-site or remote structural identification without the loss of quality or confidence in results. This would be helpful at ports of entry in any country. A topic recommended for further research is the development of analytical schemes for fast and precise quantitative routine measurements, to distinguish between legalised Hemp with quantity psychoactive substances (Tetrahydrocannabinol) and Marijuana in the United States.

9.2.2 *Serology and DNA*

Scientific contributions of the field of serology to the law began with the ability of researchers to distinguish between blood groups called ABO blood grouping. Researchers were also able to identify blood stains through colour reaction tests, and identification of blood on crime scenes. Other discoveries involved the identification of semen, sex determination of stains, microscopic uses on stains found at crime scenes, and statistical models on the likelihood to exclude or include individuals, based on ABO grouping, as the source of blood samples discovered on crime scenes. Research on improving serological tests over the years led to many multiple peer-reviewed articles and books, with the majority of analytical schemes and validation studies to be found in the sourcebook of Gaunsslen, published through the Department of Justice.¹⁶²⁵

¹⁶²⁵ Department of Justice "Sourcebook in Forensic Serology" 1983.

Legal challenges to the scientific method in this field originally related to paternity testing, but later changed to the admission of blood grouping in criminal cases to either exclude or include individuals as source contributors of blood stains on crime scenes.

9.2.2.1 Value of Serology

Serology lost its evidential value with the discovery of DNA analyses, which had a higher discriminatory value. Similar to controlled substances, where colour tests have been replaced with more sophisticated instrumentation providing structural identification of molecules, DNA also provided results with higher confidence than ABO blood grouping. With this new knowledge and higher discriminatory value, exonerations of persons convicted on the basis of faulty or overstated ABO results, became possible. This led to questions about the validity and use of serology on crime scene samples and its value in modern biological examinations.

The thesis makes the following recommendation in this regard:

Rapid screening tests and serology should still be part of analytical schemes in crime laboratories. A positive result in a combination of each analytical test always adds value to the analytical scheme and ultimately to a final conclusion or opinion. Serology will always be a supporting aid for forensic scientists and should be used in such a way that its value is clearly defined, yet not overstated.

9.2.2.2 Growth of DNA as Golden Standard

DNA continues to grow into sophistication, as predicted by Butler.¹⁶²⁶ The process with its multiple steps of extraction, quantification, amplification, electrophoresis, and analysis had grown into an empire with multiple uses in the larger forensic community. By the start of the 21st century, the knowledge of DNA had expanded to its use in paternity testing, population and migration studies,

¹⁶²⁶ Butler "Future of forensic DNA analysis" 2015.

inherited diseases, animal pedigree determination, and agricultural food production.¹⁶²⁷ DNA testing is not limited to criminal justice only, but its uses extend to other scientific disciplines. There is, however, a continual quest to receive forensic DNA results faster from crime laboratories. Rapid DNA system technology is one such discovery that allows for faster DNA results. With technology that integrates multiple steps, results for “swab-in” to “profile out” of five buccal swab reference samples are minimised to less than 90 minutes. Faster results, however, come with a high reagent cost and possible sacrificed quality, and it is therefore important for the forensic discipline to find a balance between improved methodology, speed of analysis and cost. Many crime laboratories cannot keep up with new improved technology due to the lack of organisational financial support.

New sophisticated instrumentation also shows higher sensitivity, which means less of a sample is necessary to obtain positive results on low quantity DNA. The interpretation of DNA mixtures posed pertinent challenges for forensic scientists, as emerged from scientific literature and court hearings discussed in chapter six. It is challenging for forensic experts to confidently pair alleles into genotypes and correctly separate individual contributors in DNA mixtures, if stochastic variations occur. With low-level DNA amplification and lower sensitivity, uncertainty can increase during interpretation. The algorithmic approaches are constantly challenged in courts and a single acceptable package has not been approved by any standardising body. Technological advances increased the sensitivity in DNA profiling, but outpaced the reliable interpretation of data generated. Technology changes allow forensic scientists to use less subjective opinions and start to rely more on technology to produce answers through algorithmic coding. Challenges can also come from failed PCR inhibitors that produce weak profiles in degraded DNA samples.

The thesis makes the following recommendations to address the identified gaps:

Crime laboratories have to establish a complexity threshold to avoid poor quality data interpretation and testimony. It is important for forensic experts to know the limitations of their testimony, and clearly communicate those limitations-of-interpretation approaches to avoid improper use of DNA evidence. Stronger conclusions from challenging complex data is probably the largest future venture for the DNA discipline. It is important for crime

¹⁶²⁷ “23 ways that DNA changed the world” 23 February 2003, *Independent*.

laboratories to carefully consider the cost of new technology, sensitivity thresholds, and established algorithmic models that will support interpretation of generated data. There should also be a structure to oversee the quality in crime laboratories. If a laboratory cannot afford improved quality instrumentation as a minimum standard, the mandate for performing those cases should be revoked and directed to another entity. Enough literature exists to make informative decisions on what a DNA laboratory should or should not do when working with biological evidence, especially when working with complex DNA mixtures.

9.2.2.3 DNA Quality infrastructure

The DNA testing quality infrastructure in forensic crime laboratories is one of the most advanced structures in any of the other forensic disciplines. The quality structure was built from the foundations of strong organisations, such as the European Network of Forensic Science (ENFSI), European DNA Profiling group (EDNAP), Federal Bureau of Investigation's DNA Advisory Board (DAB), Scientific Working Group on DNA Analysis Methods (SWGDM), and more recently, Organization of Scientific Area Committees (OSAC). With such a strong structural foundation on quality assurance and quality control, it is difficult to believe that not all forensic DNA entities are accredited or forensic experts working in those laboratories are certified. It can again be attributed to the lack of regulation from Justice Departments. The value of independent endorsement through accreditation will demonstrate competence to the court when performing specialised tasks.

The thesis makes the following recommendation to address the identified gap:

For admissibility of DNA evidence, all laboratories performing DNA analysis should be accredited. The value of independent endorsement through accreditation will demonstrate competence to the court when performing specialised tasks. Accreditation will ensure regular assessments, by picking up non-conformance or non-compliance within the laboratory that

might have been overlooked. Accreditation bodies also provide additional support and technical advice, online resources, training courses, and access to published scientific papers.

9.2.2.4 Research opportunities

Despite millions of dollars spent in the last three decades on DNA research, it is disappointing that the forensic community still experiences so many challenges within the discipline. There may be a variety of reasons for this, as was pointed out in chapter six of the thesis, such as: insufficient distribution of research papers within the community; lack of interest from practitioners to study research papers to decide whether new techniques may work within their crime laboratory; lack of accountability on poor research efforts, cutting the financial support to those entities; and the inability to accept change and adopt new ideas that may work. It might also be contributed to lack of financial support to acquire new instrumentation or consumables. Future research should continue to focus on higher capacity results in shorter turnaround times, which are cost effective with simplified data analysis and interpretation. Funding should be allocated to successful researchers who produced acceptable results through research papers in peer-reviewed journals. Crime laboratories should collaborate with academia, as there is presently a disconnect with regard to what is routinely needed in the crime laboratory, and what specific interests the academic researcher should be pursuing. Grant funding might support development of new sophisticated instrumentation, while underfunded crime laboratories are still struggling on knowledge of existing technology. This gap will increase unless training models and funding are associated with new developments and implementation of the technology.

Familial DNA searches still have a long way to go before they are implemented on a national and international level, but have shown promising results in the United Kingdom during the last decade. Privacy challenges arising in many jurisdictions often involve controversial language (e.g. PM versus FDS searches) used in policies and procedures relating to Familial DNA database searches. Additional research is also necessary on Next Generation Sequencing that shows some promise, but this may be too expensive for the average crime laboratory. As far as forensic ancestry testing using Y-chromosome markers are concerned, future work needs to provide a

better grasp of the geographic distribution of many of the recently discovered Y-SNPs, to establish how useful they are for improving the geographic resolution of paternal ancestry inference. It is expected that such knowledge will allow paternal bio-geographic ancestry inference to be moved from the current level (of mostly continental resolution) to a much more detailed geographic resolution. As with Y-STRs, the limitation for Y-SNPs in multiplexing capacity of the genotyping technologies currently used in forensic DNA analysis has to be overcome, in order to take full advantage of the large number of Y-SNPs needed to infer bio-geographic ancestry on a detailed level. Here, currently NGS technologies are highly promising because of their large multiplex capacity, together with their short sequencing reads, given the single base pair nature of Y-SNPs.

Another research opportunity is to focus on a third type of genealogical DNA tests, referred to as autosomal testing. Autosomal tests may result in a large amount of DNA matches, along mixed male and female lines, each match with an estimated distance in the family tree. However, due to the random nature of which and how much DNA is inherited by each tested person from their common ancestors, precise conclusions can only be made for close relations. Traditional genealogical research, and the sharing of family trees, is typically required for interpretation of the results. Successful use of genealogical DNA matching has a long way to go and will require efforts from both a legal and scientific side.

Even with all the successes, the discipline still experiences challenges and failures, and needs to overcome the problems associated with mixture interpretation challenges. The science of DNA is well received in legal settings, yet a better integration and harmonisation between the law and science should always remain a priority. Although the biological evidence is known to yield the highest exoneration counts, it is the developments within the field of forensic science that established new methods to exonerate falsely convicted individuals on insufficient scientific evidence in the past. The scientific methodology within the discipline, if applied correctly, is valid, reliable and repeatable. The forensic community needs to continue to search for solutions on DNA mixture profiles to reach a more objective opinion when interpreting data. It is clear that a one-size-fit-all approach will not be possible, as crime laboratories have different needs and approaches when it comes to software applications in data interpretation.

9.2.3 *Latent fingerprints*

Evidence on the uniqueness and permanence of fingerprint ridge flow activities and patterns was the focus of chapter seven. The formation of those patterns starts before birth and do not change until death, unless altered through diseased, manipulation or medication. The discipline developed an analytical scheme, known as ACE-V, to provide guidance for examiners to follow a specific path when performing comparisons and reaching conclusions. The ACE-V methodology is well defined outside and inside the courtroom and, if applied correctly, will produce repeatable and reliable results during friction ridge examinations. Comparisons are not just confined to minutiae points that correspond between an unknown and a known print, but expand to multi-level comparisons and observations. It is, therefore, challenging to only quantify the number of minutiae points as a measure of identification. Many statistical models and approaches have been explored for probability values or likelihood ratios, but none of them received acknowledgement by the larger fingerprint community to apply in report writing or testimony.

9.2.3.1 Value of fingerprint evidence in criminal proceedings

A vast amount of research articles has been published during the last century, within forensic science and within the wider medical field, to validate the scientific foundation of the variability to distinguish individuals. However, scientific literature indicates low likelihoods of individuals sharing a large number of common features, but not an adequate basis for assessing the rarity of a particular feature, or sets of features found in a print.

The amount of matching features and the types of features necessary to establish the potential donor pool to a single source provide for some uncertainty. This uncertainty supports the inadequate scientific foundation towards individuality when examiners draw definitive conclusions.

Although the AAAS recommended research on the frequency on individual fingerprint characteristics in various human populations to reduce the uncertainty, pattern distribution and

frequencies of features continue to show no distinguished differences between populations to provide probative value to the evidence.¹⁶²⁸

The thesis makes the following recommendation in this regard:

More research is necessary to provide qualitative methods for the estimation of probative value or weight of fingerprint evidence in criminal proceedings.

9.2.3.2 Examiner training and black box studies

A body of research exists that supports the foundation on the amount of variation possible in latent prints during deposition on various substrates. There will never be a perfect agreement between two prints from the same source, because of the elasticity of friction ridge skin. It is important for examiners to understand friction ridge source to latent print variability to determine accurately whether a given difference between print comparisons was caused by distortion or actually reflects a difference in the underlying ridge patterns.

The thesis makes the following recommendation to address this identified gap:

Comprehensive training is needed within training modules to emphasise reasons between dissimilarities or differences due to variances caused by, for example, deposition pressure, distortion, etc. Variances should also be added into blind proficiency tests to determine the competency of the examiner to demonstrate their understanding of the influence of variances during deposition transfers. The lack of proper training can lead to inconsistency between examiners, which will increase error rates in decision-making. This was highlighted through black box studies and contributed to a higher than expected false negative error rate.¹⁶²⁹¹⁶³⁰ The PCAST and AAAS called for more similar studies to get a deeper understanding of the subjective decision making processes of experts.

¹⁶²⁸ Chen “Beyond Minutiae” 2009.

¹⁶²⁹ Ulery “Accuracy and Reliability” 2011.

¹⁶³⁰ Ulery “Repeatability and Reproducibility” 2012.

9.2.3.4 Validation of databases

The algorithmic application for comparison is not known by the larger scientific community due to the sensitivity of information kept on these databases, as it should be. However, the NIST plays an integral part regarding the success of the accuracy of databases through periodic evaluations of the systems.¹⁶³¹ The accuracy of any database is determined by the quality of the data that is uploaded. If the fingerprint quality is sub-standard, then good matches will be unlikely. The NIST developed a quantitative measure-of-quality tool¹⁶³² for ten-prints of known sources, but a quantitative measure-of-quality tool is lacking for latent prints. Some researchers^{1633,1634,1635} made attempts to create such a tool, but more work is required in this field. Until such a tool is designed to accurately compare latent prints to ten-prints objectively, the discipline has to rely on well trained human observations.

The thesis makes the following recommendations in this regard:

Software designers need to work with academia and statisticians to develop and validate probative values to fingerprint evidence using comparison algorithms. The only reliable source to use to generate quantitative estimates of the probative value of print comparisons, is AFIS. Although AFIS systems are not designed to provide such statistical measures, adding such features to the software might strengthen the probative value. Efforts to accomplish these efforts have been made by CSAFE on patterned evidence and should continue in the future. As more data is added, probative values will provide better support for inclusion or exclusions of same source contributions. It will also be a step closer to objective rather than subjective conclusions.

¹⁶³¹ NIST <http://www.nist.gov/itl/iad/ig/fingerprint.cfm> (Date of use: 30 September 2019).

¹⁶³² NIST http://www.nist.gov/itl/iad/ig/bio_quality.cfm (Date of use: 30 September 2019).

¹⁶³³ Hicklin *Latent Fingerprint Quality* 2011. Also, As the PCAST report noted (PCAST, 2016, [97], n. 288), promising work in this area has been done by Hicklin et al. (2013), who developed what they call the Latent Quality Assessment Software (LQAS), a tool for evaluating the clarity of prints; and by researchers at the University of Lausanne, who are developing a quality metric and statistical assessment tool for latent prints that they call the Picture Annotation System (PiAnoS)(<https://ips-labs.unil.ch/pianos/>) (Date of use: 12 September 2017).

¹⁶³⁴ Yoon "Latent Fingerprint Image Quality" 2013.

¹⁶³⁵ Kellman "Forensic Comparison and Matching" 2014.

It has been determined that judgements or decisions made by experts are influenced by irrelevant or inappropriate information.^{1636,1637,1638,1639} This is particularly of concern during any subjective decision-making process. There are a couple of ways for crime laboratories to prevent too much information reaching the expert before any decision making is performed.

The thesis makes the following recommendation in this regard:

The expert should not be exposed to the ten-print of the suspect before looking at the latent.¹⁶⁴⁰ Context management procedures or policies should be implemented to minimise the amount of information that would reach the examiner prior to any examinations.^{1641,1642,1643,1644} The FBI already adopted such procedures for latent print analysis.¹⁶⁴⁵ Context management procedures or policies should form part of the quality management system and be audited appropriately.

Latent fingerprint examination has been performed by examiners for more than a century, but assessing the accuracy of examiners is a fairly recent practice.^{1646,1647,1648,1649,1650} The studies showed false identifications as low as 0 to 2.6 % and false exclusions from 2.9 % to 28 %. The data retrieved showed that latent fingerprint analyses are repeatable, reproducible, and

¹⁶³⁶ Dror "Why Experts Make Errors" 2006.

¹⁶³⁷ Dror "Contextual Information" 2006.

¹⁶³⁸ Dror "Quantifying the Reliability" 2008.

¹⁶³⁹ Expert Working Group on Human Factors in Latent Print Analysis, 2012.

¹⁶⁴⁰ Dror "Context Management" 2015.

¹⁶⁴¹ Cole "Forensic Science Reform" 2013.

¹⁶⁴² Found "Irrelevant Context Information" 2013.

¹⁶⁴³ Stael "Minimizing Contextual Bias" 2014.

¹⁶⁴⁴ Thompson "Investigative Facts" 2011.

¹⁶⁴⁵ Office of the Inspector General U.S. Department of Justice. (2006). A Review of the FBI's Handling of the Brandon Mayfield Case. Office of the Inspector General, U.S. Department of Justice, Washington DC, [1-330].

¹⁶⁴⁶ Kellman "Forensic Comparison and Matching" 2014.

¹⁶⁴⁷ Langenburg "Judgements of Fingerprint Analysts" 2012.

¹⁶⁴⁸ Pacheco "Miami-Dade Research" 2014.

¹⁶⁴⁹ Thompson "Human Matching Performance" 2014.

¹⁶⁵⁰ Ulery "Accuracy and Reliability" 2011.

accurate.¹⁶⁵¹ For the court, the emphasis should be on whether the expert has applied the method properly.¹⁶⁵² The AAAS has drawn three conclusions from accuracy studies:

- Performance improves with training;^{1653,1654,1655}
- Performance varies depending on the difficulty of the comparison;^{1656,1657,1658} and
- Performance varies across examiners^{1659,1660}

Some of the criticism regarding fingerprint validity and reliability has drawn attention to the fact that the error rates observed through these research studies do not reflect the rate of error in actual practice.^{1661,1662,1663} A limitation of these studies is that the examiners know that they are being tested, similar to proficiency testing, leading to additional efforts on their side to enhance their performance.¹⁶⁶⁴ Examiners may lower their threshold for decision making, which might be higher during actual practice.

The thesis makes the following recommendation in this regard:

¹⁶⁵¹ PCAST, 2016, [4].

¹⁶⁵² The PCAST report suggests that its concept of “foundational validity” corresponds to the legal requirement in Rule 702(c) of the Federal Rules of Evidence that the expert testimony be the “product of reliable principles and methods,” while the concept of “validity as applied” corresponds to the legal requirement in Rule 702(d) that “the expert has reliably applied the principles and methods to the facts of the case.”

¹⁶⁵³ Langenburg “Judgements of Fingerprint Analysts” 2012.

¹⁶⁵⁴ Tangen “Identifying Fingerprint Expertise” 2011.

¹⁶⁵⁵ Thompson “Expertise in Fingerprint Identification” 2013.

¹⁶⁵⁶ Langenburg “Judgements of Fingerprint Analysts” 2012.

¹⁶⁵⁷ Thompson “Human Matching Performance” 2014.

¹⁶⁵⁸ Kellman “Forensic Comparison and Matching” 2014.

¹⁶⁵⁹ Ulery 2014, 2016.

¹⁶⁶⁰ Hicklin “Friction Ridge Impressions” 2013.

¹⁶⁶¹ Haber “Experimental Results of Fingerprint” 2014.

¹⁶⁶² Thompson “Human Matching Performance” 2014.

¹⁶⁶³ Koehler “Intuitive Error Rate Estimates” 2016.

¹⁶⁶⁴ Informing someone that they are being tested can create what psychologists call “demand characteristics” that change the person’s responses (Orne, 1962). Individuals who know they are being tested may shift their threshold of decision in ways designed to make them look good (Paulhus, 1991). Hence, performance testing provides a more realistic picture of human performance if the participants do not know they are being tested.

The best way to overcome this problem is through “blind proficiency” testing, where proficiency tests are assigned to experts not knowing that it is a black box study or proficiency test. This will require good communication between law enforcement and laboratory/quality managers. It will also require the ten-prints of the “fake suspect” on the local or national database. Similar exercises have been conducted in DNA analysis, but these require a lot of time and are expensive.¹⁶⁶⁵ Blind proficiency testing should also be managed under the auspices of quality management and be part of certification programs.

The DOJ announced an approved, uniform language for testimony and reports for the forensic latent print discipline, at the Annual American Academy of Forensic Sciences in February 2018.¹⁶⁶⁶ Even after the publication of the DOJ document on defining identification, the larger public and the AAAS criticised the language of “identification” as non-scientific, logical, or a linguistic difference, which will not make any difference to the lay person. In a recent paper, Simon Cole¹⁶⁶⁷ expresses concerns on the new language recommended by the DOJ, especially on the use of the categorical reporting term, “identification”. This issue will remain a contested one until a real solution surfaces, but for now, opposing sides will agree to disagree and will leave it to the court to decide on the value of the fingerprint evidence. The discipline has acknowledged that the value of evidence can be overstated or understated and that more research in this regard is required to quantify the language to provide a distinct value to fingerprint evidence.

9.2.4 *Firearm and toolmarks*

The science underpinning forensic firearm and toolmark examination, as well as leading legal cases challenging the validity of the science in this field are discussed in chapter eight. The fundamental tests in this discipline were and still are the statistical foundation of reproducibility of markings and the individuality of markings between the firearm as tool and discharged cartridge cases.

¹⁶⁶⁵ Peterson “Blind DNA Proficiency Testing” 2003.

¹⁶⁶⁶ Press Release No. 18-213, Department of Justice Office of Pub. Affairs, Justice Department Announces Plans to Advance Forensic Science (Feb. 21, 2018).

¹⁶⁶⁷ Cole “Approved Uniform Language” 2018.

9.2.4.1 Number of test fires needed

Secondary to these foundations is the amount of test fires needed to ensure enough evidence is gathered by the examiner to make inferences that represent the variability present within the firearm. Although two or three are recommended, these numbers hold no justifiable empirical value.¹⁶⁶⁸

The thesis makes the following recommendation in this regard:

Law and Morris¹⁶⁶⁹ suggest two additional research topics that should be explored in order to get a better understanding of the number of test fires needed, namely the:

- Determination of the most appropriate bounds for equivalence in both distribution location and dispersion, and
- Calculation of likelihood ratios.

This will allow for a statistical understanding of inter-variability between test-fires before comparisons are made with the crime scene samples. Once the examiners know where these variabilities are coming from between test fires, it could explain the absence of markings on crime scene evidence.

9.2.4.2 Improved 3D technology

The most current technological addition to firearm and toolmark laboratories is confocal microscopy used in reflection mode.¹⁶⁷⁰ The instrument allows for the detection of variations in surface height and topography when the surface is virtually scanned along the optical axis of the microscope. A topography image of the breechface impression, firing pin and aperture shear shows remarkable detail for examiners to visualise during examinations. Conventional 2D optical images are largely affected by lighting conditions (light source, lighting direction, intensity, colour,

¹⁶⁶⁸ Virginia Department of Forensic Science, Firearm/Toolmark Procedures Manual 2019.

¹⁶⁶⁹ Law "Number of test fires" 2017.

¹⁶⁷⁰ ISO "Geometrical product specifications (GPS) *Surface texture*" 2019.

and reflectivity of the material), whereas 3D technology overcomes those limitations. The field of imaging is constantly evolving and databases using confocal microscopy imaging are currently developed by NIST for future use by crime laboratories to assist in casework analysis. Once established, it will be a more reliable source for comparison than the traditional 2D approaches currently in practice.

The thesis makes the following recommendation in this regard:

Crime laboratory supervisors should determine a balance between the use of traditional 2D comparison microscopes and/or adding new 3D imaging for comparison. More research is required to validate the software associated with 3D imaging and enhancements. Researchers should seek assistance from NIST when conducting research in this area. Open sources from NIST will allow for access to already established datasets that can be used in validation studies.

9.2.4.3 Structured research efforts

Some of the papers published in the AFTE Journal would have had greater value if the authors had a better understanding of research methods and statistical inferences associated with the data retrieved. Since the NAS report and the PCAST report, remarkable progress has been observed with actual empirical values that contribute to the scientific foundation of the evidence, and comply with the Daubert requirements.

The thesis makes the following recommendation in this regard:

Under control of the Department of Justice, entities such as the NIST, CSAFE and other academic contributors, crime laboratories should be more open to collaborative research efforts with their case samples and data images from completed cases. Practitioners will learn more on statistical methodology and practices, and in return, researchers will have a better understanding of the challenges practitioners are facing with real casework samples. Mutual research efforts will strengthen the discipline of firearm and toolmark examination.

9.2.4.4 Proficiency testing

Well-structured proficiency testing is lacking in the field of firearm examination. Research studies have shown some variability on projectiles and cartridge casing discharged from the same firearm. Traditionally, proficiency testing was based on the concept of discharging ammunition from the same firearm and sending it to various laboratories for same source identification. However, it did not take in account the variabilities and transfer damages associated with the processes. What may have been an easy comparison for one examiner because of good quality markings, could have been more challenging for the next examiner due to quality changes during transit.

The thesis makes the following recommendation in this regard:

Repeatability on proficiency can be accomplished by using one of two methods:

- Providers of proficiency tests can generate replica moulds from a single discharged projectile or cartridge and send it to multiple examiners with the expectancy to receive similar answers with the same difficulty level.
- With the development of measured 3D surface topography, analysis can now be performed on the computer without physical access to the original working evidence. Sample images are captured on a central place and the images distributed nationally or internationally, known as a process called virtual comparison microscopy (VCM). This technology allows for instant access to remote or historical data, without transferring the physical evidence to the laboratory. Digital files of the original evidence can be transferred without the possibility of transfer damages.

9.2.4.5 Improve scientific knowledge of examiners

Examiners in the discipline of firearm and toolmark examination will need to enhance their knowledge and understanding of surface topography and the importance of similarity as a surface property in this field. Merely showing images which display similarities in the courtroom will soon not be sufficient for the acceptance of the evidence as admissible by courts. Automated systems with their associated algorithmic and parametric findings on individualised characteristics on

topographic surfaces, as well as the quantitative value in similarity, will need to be explained scientifically.

The dissertation makes the following recommendation in this regard:

Certification should become mandatory for examiners who practise in the field. A program recommended by AFTE should be adopted by every crime laboratory with a re-certification interval of every five years. This will ensure that examiners stay current with improved scientific knowledge and new technology within the discipline.

Similar to fingerprint examination, the validity of the pattern evidence has been established for many years. The developments on optics allow for a better understanding of surface topography in the field, and provide higher confidence among examiners. As more studies continue to be published on the validity of 3D automated systems and the use of confocal microscopy, as well as other imaging technologies, the migration to 3D automated systems will increase, phasing out the traditional 2D systems.

Although many challenges in the field relate to subjective observational methodology, a demand for objective methods of identification (referring to known error rates and statistical reliability), began receiving more attention in the last decade. The focus has turned to the creation of statistical algorithmic capability on comparing toolmarks to determine statistical similarity, and in the process, develop an ability to separate matching and nonmatching toolmarks.

9.3 Problems of commonality between forensic disciplines

Scientific knowledge gained from each of the four forensic science disciplines is evident from their diverse and unique backgrounds and foundational development. It would therefore be impossible and unfair to make a direct comparison between these disciplines or to think that one discipline could solve the problems in another. Different analytical schemes are used in each of these disciplines that have been developed, tested and validated either through research or specific legal challenges over time. There are, however, problems of commonality between them that are summarised in the sections below.

9.3.1 *Incompetent or inept experts*

Human fallibility will always be present in product manufacturing or analytical testing. From time to time, some individuals may cause reputational harm to the profession either through unknowing mistakes or through unethical behavior. The only way to limit these is through effective supervision and effective communication within the crime laboratory and the larger forensic science community. Laboratory directors and supervisors should proactively implement risk assessment plans as part of quality control within each discipline they manage. Any form of misconduct or unethical behavior should be identified internally and dealt with immediately. A transparent corrective action plan stating the problem and the correction made should be placed on the relevant organisation's website, similar to that of the Houston Forensic Science Center. When an expert is confronted in court about mistakes made in the laboratory, transparent events of incorrect actions and corrective actions will show that the laboratory was proactive in identifying any fallibilities and corrected them.

Overreaching is another concern during expert testimony. Examples during the last decade include "testimony of a 100 per cent certainty", misinterpretation of data, testimony outside the scope of the expert's field, to name a few. Rigorous mock trials should be part of crime laboratories' culture and random testimony should be presented in front of supervisors, quality representatives and representatives from various disciplines. Laboratories should also regularly invite legal professionals and administrative staff to attend mock trial testimonies. The combination of input from all these representatives will provide better informed feedback experience on as would be the case with feedback from representatives from the specific discipline only.

With fast-paced technological developments, crime laboratories are constantly challenged to replace outdated instrumentation, and more importantly, to keep their scientists' knowledge current through further training and development. With budget constraints and the cost of external training interventions, scientists may easily fall behind in their ability to defend results using outdated equipment. Many vendors of equipment and software provide free web training and tutorials to assist crime laboratories, but scientists do not receive credit for attending or utilising these.

A number of scientists may not have a strong foundation in statistics and may easily be overwhelmed when confronted with Bayesian theorems or other statistical theorems surface. A good grasp of statistical approaches will provide a good foundation for supporting conclusions. Stronger supporting conclusions using probabilistic approaches can only be accomplished if the scientists understand the principles of the software used, as well as knowing the limitations associated with the software. The meaning of the results should also be communicated clearly to legal professionals, juries and judges. This should include good record keeping, communicating limitations of methods, models, assumptions made, and interpretations applied to the final results. Forensic scientists should stay current with technological changes. Even if the equipment used in their laboratories might be outdated, they might be questioned about new developments in the field during court hearings. A well-established scientist is recognised by his or her ability to stay abreast of developments in the discipline and participate with his or her peers on a regular basis in events relating to the latest scientific developments in their domain.

9.3.2 *Acceptance of new technology*

New technologies are regularly introduced and validated to expand the capabilities of laboratories working to recover results with improved sensitivity. Forensic laboratories have embraced automation, for sample preparation and data interpretation, in order to meet increasing throughput demands. This also contributes to more objective searching and interpretation than traditional subjective observations.

New technology should first be tested to withstand the larger science community before it is rolled out in smaller crime laboratories. The “trial-and-error” phase is over and better coordinated implementation processes are required to replace older techniques.

Laboratory managers should also define a balance between the value of the new technology and its contribution to the current analytical scheme before replacing older methodology. If the older technology is still fit for purpose, then there is no need to replace it. There should also be a balance between cost, quality and sensitivity of new technology. Legal professionals should also be prepared in advance when new technology is to be introduced within a jurisdiction. Judges may

see the technology as a new or unknown technique and rule it as inadmissible during pre-trial Daubert hearings. The change of technology should also be part of information sharing under Brady rules, notifying defence council of the new methodology followed.

9.3.3 *Interpretation of data*

It is expected that no one single expert system or software data interpretation package will be adopted by any single forensic community. Different laboratories have different needs and resources, and diversity in methodology can be expected. This reflects the view that there is no one true LR and the statistics produced will depend on the models' parameters and assumptions. In the context of forensic science investigations, different software can be used to cross-check the results for a given case, and this is a practice that should be encouraged. Comparative studies on large datasets, representative of the challenges encountered in casework, will further help the understanding of the advantages and limitations of the different systems. Such comparisons are essential, as they will assist forensic laboratories to choose a particular system that will complement their internal procedures, their validation criteria, and the workflow. Once laboratories have consensus on a particular system, jurisdictions can with confidence admit the evidence as scientifically valid.

9.3.4 *Outreach programs with legal professionals*

For many years, concerns were expressed about the lack of understanding of forensic science among judges and lawyers. Anecdotal opinion suggests that legal professionals often enter law schools in order to avoid mathematics and science, but later in their careers have to face the exact thing they tried to avoid.

Faigman¹⁶⁷¹ states that the scientific sea is very wide and deep and judges should at least know how to swim i.e. "have the basic skills necessary to read and understand scientific methods and to

¹⁶⁷¹ Faigman "Mapping the labyrinth of scientific evidence" 1995.

integrate scientific knowledge in their legal decisions, without actually having to make the swim across the entire breadth of science”. However, since 1995, the breadth of knowledge through scientific research has exploded in such a way that not even scientists are able to keep abreast with all the new developments. Meintjies van de Walt¹⁶⁷² states that “[k]nowledge of the different theories, as well as the way in which the law views science, is crucial to participants in the legal process when scientific evidence is introduced.” The myth of the existence of autonomous, unambiguous and objective scientific truths must be dispelled. More so, judges are faced with making decisions as “gatekeepers” in regard to scientific and expert testimony. It is therefore important for legal professionals to understand the scientific fundamentals underpinning forensic evidence. It is also important for legal professionals and judges to understand the technological advances made when it will be applied in their courtrooms. Earlier efforts made by the National Institute of Justice in 2012 resulted in a training module called “DNA for the Defense Bar”,¹⁶⁷³ allowing legal professionals to enrich themselves on the basic knowledge of DNA evidence. Koen and Bowers’¹⁶⁷⁴ book, “Forensic Science Reform: Protecting the innocent”, for example, assists in simplifying complicated scientific information for attorneys and judges, as well as assisting prosecuting attorneys on the state of forensic sciences in order to avoid reliance on legal precedent that is lagging behind the science. In 2016, the United States Department of Justice proposed a number of standards for expert testimony in forensic disciplines, which were challenged by the PCAST report later in the same year.

Efforts made by the West Virginia University Law School, in collaboration with the WVU Forensic Department, to create an L.L.M in forensic science, sadly received little interest from the legal fraternity and was placed on hold after three years. Besides these efforts, other programs on a regional and state level offer annual one- or two-day courses to educate legal professionals on forensic science. If it takes two years of foundational STEM courses for scientists to become forensic scientists, a two-day course will provide a bare minimum of information to a legal professional in the criminal justice system. Justice departments should audit the current state of affairs within the justice system and determine what the standardised minimum requirement of

¹⁶⁷² Meintjies-Van der Walt “Expert evidence in South Africa” 2003.

¹⁶⁷³ National Institute of Justice *DNA for the Defense Bar* 2012.

¹⁶⁷⁴ Koen “Forensic Science Reform” 2016.

training for legal professionals practicing in criminal proceedings ought to be. There are jurisdictions that understand the need to establish Forensic commissions, such as the Texas Forensic Science Commission, which consists of Judges, prosecuting and defence attorneys, forensic scientists and academics that promote training and developments amongst all stakeholders within the criminal justice system.¹⁶⁷⁵

As stated repeatedly in this thesis, legal professionals should find ways to work closer with scientists to exchange legal and scientific challenges. Both entities need to collaborate more closely to establish a uniform linguistic dictionary where words such as “error” has the same meaning in all legal proceedings across jurisdictions. This concordance of terms and definitions should be regularly updated.

Understanding the basic terminology and methodology will assist in the formulation of better legal arguments in the courtroom and will test the science and those testifying about it more efficiently. It will provide justification for an adversarial system and not just a one sided presentation of evidence. The scientific value should be clearly understood by juries to make informed decisions about the evidence.

9.3.5 *Impact of legislative changes*

Changes in legislation have a large impact on any crime laboratory and practitioners performing analytical work. Examples to this effect were observed in the discussion of legislation on controlled substances, where language on interpretation caused confusion between law and science. When new legislation is drafted, a language barrier can be avoided when scientists are invited to participate in the drafting process. The impact of the new legislation should also be discussed with all stakeholders that will be impacted by the new law. A recent change in US legislation with regard to the legalisation of Hemp with a psychoactive compound concentration lower than 0.3 %, caught many crime laboratories off guard. Quantitative analysis of plant materials are not routinely performed in crime laboratories, but the legislation change will now require every marijuana plant to be quantitated. No guidelines were provided legislation as in support of the legislation regarding

¹⁶⁷⁵ Texas Judicial Branch Texas Forensic Science Commission.

the heterogenic composition of the plant to be sampled, dryness of plant before sampling and the chemical changes within the plant during cultivation and drying phases. This is only one example of the miscommunication between law and science, with an extended implementation and interpretation problem.

The thesis makes the following recommendation to address this gap:

Changes in legislation will have an impact on the crime laboratory, the practitioner and the larger community. Legislators need to consult with all stakeholders when drafting legislation and inform stakeholders in advance when the new legislation will be enacted, as well as what the impact of the legislation on the field will be. This will allow crime laboratory directors and practitioners to be proactive and not reactive when acts are put into operation.

9.3.6 *Admissibility of evidence and expert testimony*

Chapter three focuses on the admissibility of evidence and expert testimony in various jurisdictions. Landmark judgments, such as those in *Frye*, *Daubert* and *Khuma Tires* provide sufficient guidelines courts must follow to ensure that “junk science” does not enter court hearings. Rules of evidence underpin these guidelines, addressing the required quality of knowledge of practitioners. Unqualified practitioners will be exposed by the relevant systems, albeit inquisitorial or adversarial. National and international standardisation of analytical schemes provides legal professionals with a benchmark to measure methodology used against, ensuring that quality in courts is upheld.

9.4 **Professional structuring of forensic science**

9.4.1 *NIST– OSAC - ENFSI*

Justice departments should continue to fund standardisation entities to ensure that the highest quality standards and practices are designed within the profession. Current structures within the OSAC committees are working well, allowing a comprehensive and transparent path for standards to be developed, criticised, tested and re-designed before being registered as an ASTM standard. Even the rotational membership serving on OSAC is well structured, allowing new ideas and perspectives to enter into existing models. The process in getting standards registered may be cumbersome, but it is done correctly.

The thesis makes the following recommendation in this regard:

More emphasis needs to be placed on the mandatory adoption of ASTM registered standards within crime laboratories. ASTM standards should form part of quality management systems to reach their ultimate value.

9.4.2 *Standardised certification*

The number of certified practitioners in any of the forensic disciplines is alarmingly low. Although studies discussed earlier in latent print comparisons show little difference in how certified and uncertified examiners perform on “black box” studies, it is always beneficial for the examiner who can show independent endorsement of their skills and knowledge on the subject matter. Investing in certification provides additional value to the practitioner as an expert in that discipline. Certification entities also provide additional support to ensure certified examiners stay current and also abreast with regard to changes and challenges within the discipline. Crime laboratory directors should follow the lead taken by the Texas Forensic Science Commission and implement mandatory accreditation of their laboratory and certification for all their examiners.

The thesis makes the following recommendation:

The certification should encompass a written examination on theory, statistics and ethics, followed by practical challenges and troubleshooting exercises, mentor and mentee programs, and lastly, blind proficiency testing. When a practitioner practices unethically, the certification should be revoked and the practitioner be sanctioned from the profession for a period of time. The sanctions should apply to professionals on both sides of counsel. Mandatory certification should be required of crime laboratory directors.

9.4.3 *Forensic Science Commissions*

The establishment of the Attorney General's National Commission on Forensic Science's (NCFS) 2013 was a positive step for the profession, but under a new administration the charter expired in 2017, and was subsequently not renewed. The Commission was a voice to the Attorney General

in the United States and expressed views for forensic policy considerations at the Federal level. One of the most valuable results of the Commission was to take discussions of critical issues within forensic science out of the “silos” found in particular disciplines and professional groups, to a broader scientific community and public. The Commission provided a platform for all stakeholders in an adversarial legal system to discuss issues, establish common grounds, and find solutions for policy recommendations to strengthen the criminal justice system. The Commission also focused on issues of laboratory management, oversight, accreditation, certification, and documentation and reporting of analytical results. The three key areas highlighted by the Commission that should still be pursued in the path forward are foundational, operational and relational, namely:

- Strengthening the foundational underpinning of forensic disciplines through research and development.
- Providing national guidance on evidence preservation and retention.
- Providing proper training models for forensic science users, such as law enforcement, lawyers, judges, and the public.

Although the Commission’s duration was brief, it laid a foundation for states in the United States to continue this work locally. A number of states implemented local commissions (such as the Texas Forensic Science Commission, the New York State Commission of Forensic Science and the DNA Subcommittee) to oversee and investigate complaints about misuse or neglect regarding crime laboratories.

The thesis makes the following recommendations in this regard:

Every state or criminal justice system should appoint a Forensic Science Commission and the size of the commission should be determined by the relevant state or system. It should consist of legal professionals, law enforcement, practitioners, academia and other stakeholders. Commissions should continue the work of the National Commission, as well as address local complaints within their systems. Chair’s and representatives of Commissions should meet nationally on an annual basis to discuss work done, corrective actions taken and new policies recommended. Other states can utilise the information and take it back to their respective jurisdictions for recommendations or to the Attorney General for recommendation as federal

policy. This will allow for jurisdictions to be proactive and perform risk assessments prior to problem surfacing locally.

9.5 Conclusion

Forensic Science is a profession that has for many years been struggling to be acknowledged appropriately. The breadth of scientific knowledge is comprehensive but scattered. The foundational underpinning of the four disciplines, discussed in this thesis, has been put to the legal test on countless occasions. Some gaps still remain that require further research in order to strengthen the foundation of the disciplines. Human influence will always be present in examinations and interpretations and will lean towards subjective decision making. The quality of experience and knowledge of the practitioner will contribute to the quality of the opinions or decisions made. Communication between science and law should be uniform and transparent. Legal professionals should not abuse forensic science evidence for own gain, but focus on the greater good of the facts in question. When a point is reached where all of these elements come together in harmony, the guilty will be prosecuted and the innocent acquitted.

It would be apt to conclude this thesis with the words of Richard Katskee, who wrote in an article on science, inter-subjective validity and judicial legitimacy, the following:

“Scientific evidence has special value in legal proceedings because science confers intersubjective validity that other categories of truth claims often lack. It offers factfinders and concerned observers a common yardstick against which to measure the validity and explanatory power of proffered evidence. So opinions grounded in science carry their own tests for reliability and usefulness, thus inspiring special confidence in judgments based on them. And by fostering greater public trust in legal rulings, judgments premised on scientific evidence reinforce the legal system’s ability to resolve disputes that might otherwise threaten a peaceful, well-ordered society.”¹⁶⁷⁶

¹⁶⁷⁶ Katskee RB “Science, Intersubjective Validity, and Judicial Legitimacy” 2008 *Brooklyn Law Rev* 73:857-858.

Appendix A Bibliography

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Sir Francis Bacon (1561-1626), Attorney General and Lord Chancellor of England, took up Aristotelian ideas, arguing for an empirical, inductive approach, known as the scientific method, which is the foundation of modern scientific inquiry

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Appendix B Table of Abbreviations

1,8-Diazafluoren-9-one	DFO
3,4-methylenedioxypropylone	MDPV
5-Methylthioninhydrin	MTN
Accelerated Nuclear DNA Equipment	ANDE
Admissibility Resource Kit	ARK
alphaethyltryptamine	AET
American	Am
American Academy of Forensic Sciences	AAFS
American Academy of Forensic Sciences	AAFS
American Association for the Advancement of Science	AAAS
American Bar Association	ABA
American Chemical Society	ACS
American Society for Testing and Materials	ASTM
American Society of Crime Laboratory Directors	ASCLD
American Society of Crime Laboratory Directors/Laboratory Accreditation Board	ASCLD/LAB
Analysis, Comparison, Evaluation and Verification	ACE-V
Analytical	Anal
Application	App
Article	Artic
Association of Firearm and Toolmark Examiners	AFTE
Australian Capital Territory	ACT
Australian Law Reform Commission	ALRC
Automated Fingerprint Information System	AFIS
Biology	Biol
Biology Specialist Advisory Group	BSAG
British	Br
Bureau of Alcohol, Tobacco, Firearms and Explosives	ATF
capillary electrophoresis	CE
Central Practice Note	CPN
Chemical	Chem
Circuit	Cir
Civil Procedure Rules	CPR
Colaborative Testing Service	CTS
Combined DNA Index System	CODIS
Combined Probability of Inclusion	CPI
Communication	Comm
comparison scanning electron microscopy	CSEM
Computer Vision and Pattern Recognition	CVPR

conference	conf
congruent matching cells	CMC
consecutive matching striae	CMS
Controlled Substances Analogue Enforcement Act	CSAEA
Cooperative Personnel Services	CPS
Criminal Justice Information Services	CJIS
Criminology	Crim
cross correlation function	CCF
Delta-9-Tetrahydrocannabinol	THC
deoxyribonucleic acid	DNA
Department of Justice	DOJ
diethyltryptamine	DET
Differential interference contrast microscopy	DIC
dimethyltryptamine	DMT
Division	Div
DNA Advisory Board	DAB
DNA Criminal Intelligence Database	DCID
Doctor	Dr.
Drug Enforcement Administration	DEA
edition	ed
editions	eds
enhanced bullet identification system	EBIS
European DNA Profiling group	EDNAP
European Monitoring Centre for Drugs and Drug Addiction	EMCDDA
European Network of Forensic Science Institutes	ENFSI
European Network of Forensic Science Institutes also reacted through its	
European fingerprint working group	ENFSI-EPWG
exempli gratia (for example)	e.g.
Expert Evidence Practice Note	GPN-EXPT
Federal Bureau of Investigation	FBI
Federal Court of Australia	FCA
Federal Rules of Evidence	FRE
Federal Rules of Evidence	Fed R Evid
Fibrinogen Alpha Chain	FGA
Florida	FL
Food and Drug Administration	FDA
Forensic	For.
Forensic Science Research & Training Center	FSRTC
Forensic Science Standards Board	FSSB
Forensic Technology Incorporated	FTI
Fourier transform infrared	FTIR

Friction Ridge Subcommittee	FRS
frustrated total internal reflection	ftir
gas chromatography	GC
gas chromatography-mass spectrometry	GC-MS
General Rifling Characteristic	GRC
Genetics	Genet
Georgia Bureau of Investigation	GBI
Good Laboratory Practices	GLP
High-Performance Liquid Chromatography	HPLC
Identification	Ident
Include	Inc
Inductively Coupled Plasma Mass Spectrometry	ICP-MS
Information	Inf
Infrared Spectroscopy	IR
Institute of Electrical and Electronics Engineers	IEEE
Integrated Automated Fingerprint Information System	IAFIS
Integrated Ballistic Identification System	IBIS
International	Int
International Association for Identification	IAI
Interpol European Expert Group on Fingerprint Identification	IEEGFI
Journal	J
Latent Quality Assessment Software	LQAS
Law Journal	LJ
Law Review	L Rev
Legum Magister	LL.M
letters	lett
likelihood ratio	LR
Limited	Ltd
liquid chromatography	LC
Local DNA Index Systems	LDIS
Lysergic Acid Diethylamide	LSD
Magazine	Mag
Mass spectrometry	MS
Medicine	Med
Methamphetamine Control Act	MCA
methylene-dioxymethamphetamine	MDMA
Miami-Dade Police Department	MDPD
Mitochondrial DNA	mtDNA
National Academies Press	NAP
National Director of Public Prosecutions	NDPP

National Academy of Sciences	NAS
National Accreditation Board	ANAB
National Audit Office	NAO
National Commission on Forensic Science	NCFS
National Criminal Information Center	NCIC
National DNA Database	NDNAD
National Firearm Examiner Academy	NFEA
National Forensic Institute	NFI
National Institute of Justice	NIJ
National Institute of Standards and Technology	NIST
National Integrated Ballistic Information Network	NIBIN
National Prosecuting Authority	NPA
National Research Council	NRC
National Research Council	NRC
Next Generation Sequencing	NGS
NIST Ballistics Identification System	NBIS
Northern Territory	NT
Nuclear magnetic resonance	NMR
Number	No
Office of National Drug Control Policy	ONDCP
Organisation of Scientific Area Committees	OSAC
Original	Orig
Pennsylvania	PA
Pharmacology	Pharmacol
Phylosophy	Phylos
Physiology	Physiol
Polymerase Chain Reaction	PCR
Portability and Accountability Act	HIPAA
post-conviction relief	pcr
President's Council of Advisors on Science and Technology	PCAST
Prevention of Organised Crime Act	POCA
probability of exclusion	PE
Probability of Random Correspondence	PRC
Proceedings	Proc
Quality Assurance Standards	QAS
Queensland	Qld
Random Man Not Excluded	RMNE
random match probability	RMP
reference ballistic image database	RBID
Restriction Fragment Length Polymorphism	RFLP

Revision	Rev
Ribonucleic acid	RNA
Rhesus disease	Rh(D)
Royal Canadian Mounted Police	RCMP
Rules of Supreme Courts	RSC
Scanning Electron Microscopy	SEM
Schengen Information System II	SISII
Science	Sci
Science Technology Engineering and Mathematics	STEM
Scientific Crime Detection Laboratory	SCDL
Scientific Working Group for firearm and toolmarks	SWGGUN
Scientific Working Group for the Analysis of Seized Drugs	SWGDRUG
Scientific Working Group on DNA Analysis Methods	SWGDM
Scientific Working Group on Friction Ridge Analysis, Study and Technology	SWGFAST
Scottish Criminal Record Office	SCRO
Section	Sec
Security	Sec
Series	Ser
Service	Serv
Short Tandem Repeats	STR
Single Nucleotide Polymorphisms	SNP
Society	Soc
South Australia	SA
State DNA Index Systems	SDIS
Supreme Court of New South Wales	NSWSC
Supreme Court of the Australian Capital Territory	ACTSC
Supreme Court of Queensland	QSC
Supreme Court of South Australia	SASC
Supreme Court of Tasmania	TSC
Supreme Court of the Northern Territory	NTSC
Supreme Court of Victoria	VSC
Supreme Court of Western Australia	WASC
Survey Evidence Practice Note	GPN-SURV
Tasmania	Tas
Technical Working Group on DNA Analysis Methods	TWGDAM
Technical Working Groups	TWG
Technical Working Group for the analysis of seized drugs	TWGDRUG
Technological Resource to Assist Criminal Enforcement	TRACE
Tetrachlorodibenzodioxin	TCDD
Tetramethylbenzidine	TMB

Thin Layer Chromatography	TLC
Three Dimensional	3D
Transactions	Trans
Two Dimensional	2D
Ultra Violet	UV
United Kingdom	UK
United Kingdom	UK
United Nations Office on Drugs and Crime	UNODC
United States of America	USA
Variable Numbers of Tandem Repeats	VNTR
Victoria	Vic
virtual comparison microscopy	VCM
Volume	Vol
Western Australia	WA

Key Concepts

Admissibility

Controlled substances

Deoxybonucleic acid (DNA)

Drug Chemistry

Expert Evidence

Fingerprints

Firearm and toolmarks

Forensic reseach

Forensic Standardisation

Opinion Evidence