REPORT TO THE PRESIDENT
Forensic Science in Criminal Courts: Ensuring Scientific Validity of Feature-Comparison Methods

September 2016

RESPONSES TO SOLICITATION QUESTIONS

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Existing Forensic Techniques and Practices

Question 1 – Published and needed studies for pattern-based forensic science methods

What studies have been published in the past 5 years that support the foundational aspects of each of the pattern-based forensic science methods, including (but not limited to) latent print analysis; firearms/toolmarks; shoe/tire prints; bitemark analysis; questioned documents? What studies are needed to demonstrate the reliability and validity of these methods?

Itiel Dror, Senior Cognitive Neuroscience Researcher, University College of London

What has been done, but needs much more is:

1. Studying the basic reliability of forensic examiners in the perception of the evidence (before comparison and decision), e.g., how many minutia are present in a fingerprint – see provided reference.
2. Studying the basic reliability of forensic examiners in the forensic decisions (e.g., the conclusion of DNA interpretation) – see provided reference. This is very different than point 1 (above): one deals with the basic perception of the evidence, and one with the comparison of the evidence to a suspect and concluding an identification (or not).
3. Studying factors beyond basic reliability, such as biasing effects of irrelevant contextual information. – See provided reference that has data on these and distinguishes between reliability and bias-ability.

Stephen E. Fienberg, Professor of Statistics and Social Science, Carnegie Mellon University

The study by:
Neumann, C., I. W. Evett, and J.E. Skerrett (2012). Quantifying the weight of evidence from a forensic fingerprint comparison: a new paradigm (with discussion). Journal of the Royal Statistical Society: Series A 175(2), 371-415, is an interesting example of progress in thinking about fingerprint evidence, but as the discussion makes clear, enormous amounts of work remains if this type of approach is to become viable and reliable.

Steven Johnson, Board Chair, The International Association for Identification

There have been a number of "white box" and "black box" studies utilizing latent print examiners (LPEs) to determine analysis effectiveness (include Dade County within the last two years). The results tend to show that there is a very low error rate amongst LPEs when it comes to missed opportunities for identification and even lower for "false positives". The vast majority of LPEs will err on the side of caution before making a positive identification with which they aren't 100% confident.

C. Michael Bowers, Odontologist, Ventura Medical Examiner

Empirical studies supporting human identification using bitemark pattern methods do not exist. DNA profiling has supplanted this police-developed technique which should be terminated. In fact, DNA has been instrumental in debunking court room bitemark testimony. Nearly 30 exoneration cases provide sufficient proof that bitemark opinions in any forum are a danger to public safety. See article for case study.

I want to applaud the OSTP panel for making a commitment to investigate the non-science fallacies and untested assumptions that have been in use for decades by dentists who have considered bitemark patterns to be similar to fingerprint patterns. I was trained in bitemark "matching" by the founding members of the bitemark certifying board, the ABFO. After over 20 years as a member of this small organization, I resigned in 2012 due to the group's leadership who continued to deny the serious methodology defects in their practices that led to wrongful convictions and incarcerations which allowed real perpetrators to escape prosecution. Now that a few certified dentists are still promulgating a "new paradigm" of bitemark analysis, I must caution the OSTP panel that whatever that may be promised, has negligible scientific rigor and will still present unacceptable risks to our judicial system of justice.

Joe Cecil, Senior Research Associate, Division of Research, Federal Judicial Center

I served on the National Academies' forensic science committee, and my knowledge concerning the state of forensic science is current for about 2011. These studies have been collected by the National Commission on Forensic Sciences, and an ongoing project by the American Association for the Advancement of Science, in collaboration with the ABA Committee on Science, Technology and Law. The National Academies' report, Forensic Sciences: A Path Forward reviewed the areas that require further research. The research in these areas has also been collected by the National Clearinghouse for Science, Technology & Law. Necessary additional studies in this area are those that control for cognitive bias in making the subjective assessments that are part of the pattern matching forensic sciences.

Frederick R. Bieber, Professor, Harvard Medical School

Blinded studies, free of confirmation bias, are sorely needed to study each of these pattern-based forensic science comparison methods. Moreover, intra-observer variability studies will be critical for more general acceptance of these methods.

Ahmed, PhD genetic engineering /DNA fingerprint

DNA fingerprint technology. Forensic serology science. Clinical pathology Lab. Molecular technic.

Mary Beth Hauptle, Forensic Odontologist, FCMEO

Mary & Peter Bush of Buffalo, NY did a study on bite marks made in cadaver skin to judge whether analysis of the pattern could be positively related to identity of the biter.

Melissa Connor, Director, Forensic Investigation Research Station

I have worked with master's students addressing the questions posed in the Strengthening Forensic Science volume, from how long fingerprints last on different substrates to how much use it of a tire or shoe to obliterate individualizing marks.

Tatiana Maria Blanco Alvarez, MA, Graduate student Texas Tech University

In the Journal of Forensic Sciences, as well as in different Journals from specific fields, there have been published articles about how these methods have been developed, how they comply or not with Daubert or Frye rulings, and how they are used in the field of forensic sciences.

But still there´s the need of research on validity and reliability of the methods, because many experts have been using methods that are more empirical than science based for example, research that developed specific protocols that can be followed, as well as multicultural studies.

Femblix Meek Tom Jr, Bronx Community College

National Academies Press

Strengthening Forensic Science in the United States: A Path Forward ... Analyses although the forensic use of nuclear DNA is barely 20 years old, DNA…. Friction ridge analysis shares similarities with other experience-based methods of pattern ... a training publication, Friction Ridge Skin Identification Training Manual Isaac Newtons policy 1687 1713 1726 Simple Mathematics with Fire arms examiner.

Heather Garvin, Assistant Prof of Anthropology/Applied Forensic Sciences, Mercyhurst University

This question would require extensive research to answer. New studies are constantly coming out in journals such as the Journal of Forensic Sciences, with research in various forensic disciplines - some of them presenting new research, others validating published research. The scientific community is constantly working to advance and improve its methods. If you want this answer, have a researcher spend a few days performing literature reviews in the relevant journals searching for the key words.

Pierre Margot, Emeritus Professor, University Lausanne

Provided list of references.

Mark Leney, Professor, UMass Medical School and Deputy Director, MassBiologics

I am not actively practicing forensic science but I do monitor some sub-disciplines. A number of pattern matching publications have been authored in the anthropology field purporting to match human remains post-mortem to images taken ante-mortem - principally radiographs. In these cases the statistical power appears to be low, the databases constructed are probably not generally applicable and the utility of the methods has not been widely demonstrated - that is, they are qualified for use only in a single laboratory and probably for a single problem. Publication of the reference database used and the complete record of the validation study should be made standard for such studies. This would encourage inter-lab testing and validation of smaller databases in more rarely utilized problem areas.

Eric Warren, Ph.D, Special Agent/Forensic Scientist, Tennessee Bureau of Investigation

Firearm/Toolmark Identification: While there have been numerous articles, theses, and textbooks written on the scientific validity of field of Firearms and Toolmark Identification (FA/TM ID) stretching as far back as

the 1850s, some of the most recent studies are cited below. Studies on the latest technology and manufacturing techniques would be warranted to understand and document the types of markings left on firearms by these new manufacturing technologies. Provided list of references.

Robert Gaensslen, Professor, Prof Emeritus, University of Illinois Chicago

For handwriting, see the work of Srihari at SUNY Buffalo. Also the work of Moshe Kam in J Forensic Sci. For fingerprints, see Ulery et al PNAS USA 108, No 19. There are many "consecutively mfgtd barrel" items in AFTE Journal.

There are different ways to go at the Q. Using fingerprints as an example, you could use AFIS databases to build a foundation for chance duplication probabilities. Call this the 'first principles' approach (the best one). You can also show that the results are correct, and not worry about the reason. Call this the 'correct outcomes' approach. The basic principles approach is comparatively easy with fingerprints, though I don't think it has been done. It is more difficult, maybe not possible, with bullets, cartridge cases, footwear, tire tracks, handwriting, and bitemarks. The work of Dror is important in assessing the issue of subconscious bias.

Dr. Sushil Kumar Sharma, Editor, EC Chemistry, UK

LC–MS/MS and GC–MS methods in propofol detection: Evaluation of the two analytical procedures was introduced in November, 2015 by Fabio et al. They proposed that Propofol is a short-acting hypnotic agent that is commonly used to induce and maintain anesthesia. Propofol abuse and its involvement in suicide deaths have increased in recent years, especially among healthcare personnel. An example is the suicide of a 61-year-old nurse found with a propofol drip in his left arm. We describe the postmortem concentration of propofol in various tissues (femoral and cardiac blood, bile, urine, brain, and liver) and in the drip. The toxicological analyses were performed through two analytical methods, differing in derivatization reaction and in instrumentation: silylation for gas chromatograph–mass spectrometer (GC–MS), as routinely performed in our laboratory for this kind of analyses (lower limits of quantification–LLOQ–in urine and blood: 0.3 and 5 ng/ml); for liquid chromatograph–tandem mass spectrometer (LC–MS/MS) an innovative azo-coupling derivatization (LLOQ: 0.0004 and 0.1 ng/ml). This latter produces an azo-derivative (molecular composition: C18H22ON2; molecular weight: 282 Da) highly ionizable in electro-spray ion source, both in negative and positive ionizations. These two methods were compared to evaluate the effectiveness of this new LC–MS/MS analysis. An acidic hydrolysis (HCl 6 N, 100 °C, and 1 h) was performed for the biological samples (1 ml or 1 g) irrespective of the analytical method applied. The drip content was extracted adding phosphate buffer (pH 8) and a dichloromethane/ethylacetate 8:2 (v:v) mixture. Derivatization steps were: silylation with N,O-bis(trimethylsilyl)trifluoroacetamide (BSTFA) + tetramethylammonium hydroxide (TMAH) for GC–MS; regarding LC–MS/MS, azo-coupling reaction with the aryl-diazonium salt (0–5 °C, and 30 min). The analyses were achieved in selected-ion monitoring for GC–MS (m/z, 235,250,73 propofol"; m/z, 252,267,27 propofol-d17) and in multiple reaction monitoring ([M−H]−: m/z 283→241,77, azo-propofol; m/z 299→251,77, azo-propofol-d17) for LC–MS/MS. Autopsy showed no significant findings. Propofol concentrations were (LC–MS/MS vs GC–MS, respectively): 15.1 vs 14.5 mg/ml, drip content; 7.11 vs 6.07 µg/ml, cardiac blood; 9.50 vs 7.19 µg/ml, femoral blood; 0.64 vs 1.07 µg/ml, bile; 0.042 vs 0.051 µg/ml urine; 4.93 vs 5.89 µg/g, brain; and 7.88 vs 6.80 µg/g, liver. These values are comparable with the ones described in literature for death by acute propofol intoxication; the drip content is compatible with a diluted formulation of propofol available in Italy (20 mg/ml injectable emulsion). The comparison shows an excellent fitting of the data (R2: 0.9362). Toxicological results proved the cause of death as acute propofol intoxication. Furthermore, the new LC–MS/MS method showed an excellent effectiveness and reliability when compared to the routinely used GC–MS method.

Edward Imwinkelried, Edward L. Barrett, Jr. Professor of Law Emeritus, University of California Davis

Neuman, Evett & Skerrett, Quantifying the Weight of Evidence from a Forensic Fingerprint Comparison: A New Paradigm, 175 J. R. Stat. Soc. Ser. A 1, 12 (2012)

Taylor, Dutton, Aldrich & Dutton. Application of Spatial Statistics to Latent Print Identifications: Toward Improved Forensic Science Methodologies 2, 9-10 (2012).

Rigo Vargas, QD Section Chief, MS Forensic Laboratory

Provided list of references.

Michael Kusluski, Forensic Scientist, Michigan State Police

The National Academy of Sciences made a failed half-hearted attempt at this. As a firearms examiner, there are numerous studies in my discipline. However, most have been published in the Association of Firearms & Toolmarks Examiners Journal. Because (until recently) this journal was not indexed in a database (e.g., Scopus), the interns at NAS simply assumed the research did not exist. Currently, AAAS is revisiting this issue.

Dr. L. Thomas Johnson, Professor (Retired) Marquette University

Replication of Known Dental Characteristics in Porcine Skin:
Emerging Technologies for the Imaging Specialist
NIJ 2010-DN-BX-K176
Award period October 1, 2010 – September 30, 2013

Dr. Geoffrey Steward Morrison, Independent Forensic Consultant; Adjunct Associate Professor, Department of Linguistics, University of Alberta

With limited resources to commit to the current response to the questions asked, I restrict my comments primarily to material published by my colleagues and myself, primarily in the area of forensic speech science; however, much of what I have to say is I believe also applicable across other branches of forensic science.

Forensic Science is undergoing a paradigm shift (Saks & Koehler, 2005; Morrison, 2009). Over several years my colleagues and I have developed a formulation of a paradigm for the evaluation of forensic evidence which includes the following key elements:

- Use of the likelihood ratio framework for the evaluation and presentation of the strength of forensic evidence.

This is the logically correct framework for the evaluation of forensic evidence (e.g., Robertson & Vignaux, 1995; Balding, 2005; Buckleton, 2005; Association of Forensic Science Providers, 2009; Morrison, 2010; Evett et al, 2011; Berger et al, 2011; Redmayne et al, 2011; Robertson et al, 2011; Morrison, 2012), is was adopted as standard for DNA in the mid 1990's (Foreman et al, 2003), is gradually being adopted in other branches of forensic science (including forensic voice comparison: Morrison, 2009; Morrison & Enzinger, 2013), and is recommended in the recently-published European Network of Forensic Science Institutes' Guideline for Evaluative Reporting in Forensic Science (Willis et al, 2015).

An aspect of the likelihood ratio framework that is often not well understood is that a likelihood ratio is the answer to a specific question specified by both the prosecution and the defense hypotheses. In a forensic voice comparison case, the prosecution hypothesis is usually that the speaker of questioned identity is the defendant. The defense hypothesis is usually that the speaker of questioned identity is not the defendant. The defense hypothesis is not, however, that the speaker of questioned identity is any other speaker on the planet, but rather that it is a person selected at random from a relevant population – this population will be restricted by information which can be gleaned from the recording of the speaker of

questioned identity and will include properties such as the gender of speaker and the language spoken (see Rose, 2002; Morrison, Ochoa, Thiruvaran, 2012). Case circumstances in other branches of forensic science may also restrict the relevant population. The forensic scientist must make transparent what specific question they have set out to answer so that the judge at an admissibility hearing or the trier of fact at trial can decide whether the forensic scientist has set out to answer an appropriate question, and also so that they can understand the answer that the forensic scientist provides to that question.

- Use of relevant data, quantitative measurements, and statistical models to calculate likelihood ratios.

This approach is transparent and replicable – the forensic scientist can describe what they did in sufficient detail that another suitably qualified forensic scientist can repeat what they did. In contrast, if the strength of evidence statement made by the forensic scientist is based primarily or directly on a subjective judgment, then this is not transparent or replicable.

An approach based on relevant data, quantitative measurements, and statistical models does involve subjective elements. For example: What is the relevant population for this case? Is the sample of the population sufficiently representative of the relevant population and does it adequately reflect the conditions of the case under investigation? (see discussion under "testing" below) These are pre-empirical questions which should be debated before the judge at an admissibility hearing or the trier of fact at trial. If the judge or trier of fact is satisfied, then the remainder of the analysis is objective. In the first instance it is up to the forensic scientist to satisfy themself that the data they use for training and testing their statistical models are sufficiently representative of the relevant population and casework conditions, but ultimately it is the judge and trier of fact who must be satisfied.

This approach is intrinsically much more robust to the potential effects of cognitive bias than an approach in which the strength of evidence statement made by the forensic scientist is based primarily or directly on subjective judgment. The subjective elements in an approach based on relevant data, quantitative measurements, and statistical models are far removed from the final decision as to the strength of the evidence. (See Found, 2015, for a recent introduction to cognitive bias in forensic science.)

Approaches based on relevant data, quantitative measurements, and statistical models are also practically easier to test than approaches based on subjective judgment. The former can quickly and cheaply provide responses to hundreds or thousands of test trials, whereas each subjective judgment is time consuming for a human expert.

Further discussion of all of the above is provided in Morrison & Stoel (2014).

- Empirical testing of the validity and reliability of the forensic analysis system under conditions reflecting those of the case under investigation.

Such testing is the only way to demonstrate that the forensic analysis system is actually fit for purpose (National Research Council, 2009; Forensic Science Regulator, 2014a, 2014b). Such testing treats the system as a black box and is not prejudiced against any approach whether it be based on relevant data, quantitative measurements, and statistical models, or based directly on subjective judgment. If the judge or trier of fact is satisfied that the test data are sufficiently representative of the relevant population and casework conditions, and that the demonstrated level of performance of the system using these test data is adequate, then there need be no debate regarding the internal workings of the system.

In Morrison (2011) I described suitable metrics for testing validity and reliability within the likelihood ratio framework. In Morrison (2014) I reviewed calls going back to the 1960s for the validity and reliability of forensic voice comparison to be empirically tested under conditions reflecting those of the case under investigation. The conditions of audio recordings in forensic voice comparison are highly variable from case to case:

-The relevant population.

-The speaking style on the questioned voice recording and on the known voice recording, e.g., casual conversation, formal speech, responses to police interview questions, whispering, shouting.

-Presence, volume, and type of background noise, e.g., music, traffic noise, ventilation system noise, babble.

-Presence and details of reverberation, e.g., if the recording is made in a small room with hard walls.

-Transmission of the speech signal through different telecommunications channels which affect the properties of the signals in different (generally deleterious) ways, e.g., landline telephone, mobile telephone, Voice over Internet Protocol.

-Saving audio recordings in formats which distort and lose information, e.g. MP3.

The range of possibilities is essentially infinite such that a separate test of validity and reliability is required for each case. The performance of a forensic voice comparison system under one set of conditions will not necessarily be informative as to the performance of that system under another set of conditions. For example, a system which works well under studio-recording conditions, may perform quite poorly if the audio has been transmitted through a telephone system, especially poorly if it has been transmitted through a mobile telephone system (Zhang et al, 2013). Taking the results of testing a system under one set of conditions and presenting them as informative as to the performance of the system under another set of conditions may be quite misleading. It is not appropriate to run a single validation test and then assume that this is applicable across a range of different casework conditions. Empirical tests of validity and reliability must be run in a case by case basis. To a greater or lesser extent this may also be true in other branches of forensic science.

To date, my colleagues and I have published two research papers describing the implementation of this paradigm under conditions based on those of real cases (Enzinger et al, 2015; Enzinger & Morrison, 2015). These papers include empirical tests of the validity and reliability of different forensic voice comparison systems under conditions reflecting those of two different cases. Additional papers testing the performance of other systems and other sets of casework conditions are submitted and in preparation.

Glen Jackson, West Virginia University

I'm not an expert in pattern recognition, but I am aware that many "peer-reviewed" articles appear in journals like IAI (International Association for Identification), which are restricted from public access. These articles can never been seen by non-members of IAI, so we (academicians) cannot evaluate the work.

Josep De Alcaraz-Fossoul, Researcher and Assistant Professor, University of Barcelona

Forensic science disciplines (FSD) have undergone dissimilar degrees of *scientification* in recent years, depending mostly on financial resources available. The current *scientification* process has been prompted by several factors, including our deficiency in understanding crime evidence (i.e. what information can be extracted reliably); the absence of international standards to ascertain a positive identification (i.e. how is information extracted and interpreted) and errors in evidence attributions. Our goals as forensic experts are to understand and explain what evidence is, how reliably information can be extracted and how useful that information is for the purpose of identifying crime suspects or victims.

The studies classified and listed below (in chronological and alphabetical order) are only examples of the high quality of forensic research that is being conducted. All of them incorporate techniques and/or equipment that are also used in other scientific disciplines, such as Medicine, Physics or Chemistry, including complex statistics. This demonstrates the great effort of the forensic community to make FSD as trustworthy and robust as any other “purely” scientific discipline.

See references cited.

In summary, it can be clearly stated that the binomial “forensic science” has been incorporating more “science” than “forensic” in the past years, especially in its analytical procedures. Every discipline is integrating at its own feasible path higher degrees of objectivity that are required by the current times. Nonetheless, forensic experts and other stakeholders need to be aware that the simple application or inclusion of “science” is not the Holy Grail for increasing objectivity and reliability. We must keep in mind

that scientific methods can also be applied incorrectly and can lead to erroneous conclusions. The current pressure exerted on FSD to become more scientific must not make us rush in the process of *scientification* and fail in our objective. FSD cannot afford to include wrong methods or reaching erroneous conclusions/results because of their direct implications in human lives (freedom). We should analyze the particular needs of each discipline individually. The lack of proper understanding of what is causing the problems can derive in even bigger complications for generations to come.

I would like to highlight that FSD will never be able to become as exact as Mathematics or Physics. This is because there are too many uncertainties about the crime scene at once. Every stakeholder involved (forensic practitioners, judiciary, governments, regulatory agencies, etc.) should be aware of the technical and practical limitations of FSD. Recognizing these limitations will avoid future frustrations. It is not possible to demand high degrees of *scientification* to certain FSD because they are not comparable with exact sciences (for example, forensic handwriting examinations). Having said that, I can affirm that FSD are progressing satisfactorily, even with the limited funds available.

In the era of *contemporary forensics*, I believe the more urgent studies should focus on finding methods to:

1. **Determine the age of evidence**. The *time* factor is becoming more relevant than ever before and technology is proving useful to achieve this goal. In many cases these studies will involve a better understanding of evidence themselves (i.e. chemical and physical properties). Placing a suspect within the timeframe of a crime will undoubtedly increase the reliability of evidence and that of the discipline itself. At the same time, it will minimize errors in the attribution of evidence and the reputation of the criminal justice system will undoubtedly improve.
2. **Apply proper statistics and mathematical models** depending on the intrinsic characteristics of the FSD. This includes large population studies to determine patterns or frequencies of identifiable features.
3. **Globally homogenize (or harmonize) expert's knowledge** through appropriate education and training. In many countries and regions there are no adequate education schemes for current or future forensic scientists.
4. **Establish a standard scale of expert conclusions**. Most law enforcement agencies use their own scales or types of conclusions. These can sometimes become confusing (if not contradicting) between agencies and to courts. This is especially noticeable for criminal cases involving more than one international jurisdiction.
5. **Improve the effectiveness of the transmission of information to lay persons**. Several articles have been published that question the ability of forensic experts to effectively transfer relevant results to non-experts. This existing miscommunication devaluates the experts' work and the conclusions that are being reported in court:
   - Thompson WC et al. (2015). *Lay understanding of forensic statistics: Evaluation of random match probabilities, likelihood ratios, and verbal equivalents.*
   - Mullen C et al. (2014). *Perception problems of the verbal scale.*
   - Martire KA et al. (2015). *Perception problems of the verbal scale: A reanalysis and application of a membership function approach.*
   - Martire KA et al. (2013). *The expression and interpretation of uncertain forensic science evidence: verbal equivalence, evidence strength, and the weak evidence effect.*

Angi Christensen, Forensic Anthropologist, FBI Laboratory

In forensic anthropology, most pattern-based comparisons relate to radiologic comparisons of antemortem and postmortem records to support identification of deceased individuals. Numerous studies exist that support the individual variation in radiologically-visible skeletal structures.

David Brundage, Ballistics Laboratory Director, Aegis Sciences Corporation

There have been a great number of pertinent studies in the last five year that are published in the Journal for the Association of Firearm and Tool Mark Examiners (J. AFTE) that support many foundational aspects in the areas of Firearms/Toolmarks identification. The J. of AFTE is an international refereed forensic publication and can be found by going to www.afte.org. The number of specific articles are too numerous to list in this small amount of space.

Rachel Bolton-King, Award Leader for Certificates of Professional Competence & Lecturer in Forensic Investigation, Staffordshire University

My response to this survey focusses specifically on forensic firearm identification as my area of expertise and active field of research. I currently have a professional review article entitled 'Preventing Miscarriages of Justice: A Review of Forensic Firearm Identification' currently in press with the journal Science & Justice (attached to this survey submission for you to read). The article details a response to many of the questions posed in this survey as well as many references to research published in the field within the last 5 years, which should be of interest to PCAST to broadly understand the landscape of the field of forensic firearm identification. The wider context of the article will also apply in some respects also toolmark identification as well as other forensic science pattern-recognition based disciplines.

Carl C. Stacy - Director of Forensic Sciences/Chief Medical Examiner, University of Missouri Columbia, School of Medicine

This question is best answered by asking those who work in each of these fields and by having a librarian at the NLM do a literature search. Specifically in my field of forensic pathology there is an article in nearly every journal and basic forensic pathology textbooks of the patterns such as would be seen in an injury such as blunt force injuries, gunshot wounds and so forth.

Joseph Prahlow - Professor of Pathology; Forensic Pathologist – Western Michigan University

Regarding forensic pathology specifically, there are very few "studies" that have been published that deal with pattern-recognition; however, if one expands the definition of the term "studies" to include case reports, many more might be considered in this category. Forensic pathology is the practice of medicine. Some of what we do involves "pattern-based" interpretations; however, unlike several other pure forensic science disciplines, where arguments can be made that the examiners should not be made-aware of case-related information as it could potentially result in bias, one cannot and should not place FP in the same category. One cannot practice medicine "in a black box."

Bridget Lewis - President, International Association for Identification

By way of introduction and general comment, the time frame provided was short given the breadth of your questions in terms of the amount of research effort it would take to answer them in depth. Additionally, it is critical that you understand that questions such as these have been fully researched and answered by the forensic community, including the International Association for Identification (IAI). Past responses included the Internal Working Groups, formed by the White House Subcommittee on Science and Technology, the Scientific Working Groups, working under the FBI, then NIJ, and now as the Organization of Scientific Area Committees (OSAC) working under NIST. It is imperative that government entities communicate to prevent a duplication of efforts. To answer your questions thoroughly, accurately, and properly, more time and more support would be needed.

Finally, it is extremely important that groups such as yours involve the forensic community in your initial and ongoing committee work. Your efforts are important and encouraged. It is our recommendation that in order to get the most from your efforts, you include active practitioners on your committee to provide perspective.

Foundational aspects of any object under consideration for examination are:

1. The features of objects are either repeatable or unique.
2. These objects may have their surface features recorded as details in impressions or images.
3. The features of objects need to be persistent enough between the two events of when impressions or images are made.
4. The examination method involves analyses of the first image/object, analyses of the second image/object, comparisons of the details in the two images/objects, then evaluations about the analyses and comparisons of the details in the two images/objects, followed by determining a conclusion.
5. Measurements during the analyses and comparisons are usually visual comparative measurements of details, not measurements using technology or instruments.
6. The substrate, processing technique, and technology used to capture an image must be sufficiently understood so that the examiner can differentiate between the details of the images and background noise. The quality of the impression or image of the object being compared is also affected by the quality of the recording media. Media is an important variable that needs to be taken into consideration when conducting examinations. In photographs and video, there are issues of lighting, compression artifacts, angle of recording, etc.

Some studies from the past five years can be found in the following links. (This list, as other lists in this response, is not all-inclusive.) Some of the links require a password:

1. National Institute of Standards and Technology (NIST):
    a. http://www.nist.gov/forensics/research/index.cfm
    b. http://www.nist.gov/oles/forensics/scientific_working_groups.cfm
    c. http://www.nist.gov/forensics/osac/index.cfm
    d. http://www.nist.gov/search-results.cfm?q=foundational+forensic+science+bibliography&btng=Search&num=10&sortType=L&scopeType=0&datefrom=&dateto=
    e. http://www.nist.gov/forensics/workgroups.cfm
2. The International Association for Identification (IAI), www.theiai.org, and the Journal of Forensic Identification.
3. The American Academy of Forensic Sciences, http://www.aafs.org/, and the Journal of Forensic Sciences.
4. The Association of Firearm and Tool Mark Examiners (AFTE), https://afte.org/ and the AFTE Journal.
5. The American Society of Questioned Document Examiners (ASQDE), http://www.asqde.org/, and the Journal of the American Society of Questioned Document Examiners.
6. Forensic Science International journal, http://www.journals.elsevier.com/forensic-science-international/
7. Australian and New Zealand Forensic Science Society, http://anzfss.org/ , and the Australian Journal of Forensic Sciences.
8. Canadian Society of Forensic Sciences, http://www.csfs.ca/ , and the Canadian Society of Forensic Science Journal.
9. Canadian Identification Society, http://cis-sci.ca/ , and the journal, Identification Canada.

10. The Law Enforcement and Emergency Services Video Association International, Inc., https://www.leva.org/ and their publication.
11. See the NIJ published, The Fingerprint Sourcebook, Chapter 14, Scientific Research Supporting the Foundations of Friction Ridge Examinations, https://www.ncjrs.gov/pdffiles1/nij/225320.pdf
12. The American Association for the Advancement of Science has a project about research: http://www.aaas.org/page/forensic-science-assessments-quality-and-gap-analysis
13. The National Institute of Justice has many studies linked: http://nij.gov/publications/pages/publication-list.aspx?tags=Forensics
14. Noblis has some links:
    a. http://www.noblis.org/noblis-media/case-studies
    b. http://www.noblis.org/noblis-media/highlights
    c. http://www.noblis.org/noblis-media?a=Biometric-Publications-%26-Presentations-

Studies that could be conducted to demonstrate the validity and reliability of comparative examination methods:

1. Research patterns of features within objects that have been generated through natural processes. Can natural patterns be repeated in multiple objects or are those patterns of features unique?
2. Research patterns of features within objects that have been generated by humans.
3. Research patterns features within objects that have been generated by machines
4. Research patterns of features within objects that have been generated by combinations of the above.
5. Research the ranges of levels of clarity of details that are generated in impressions or images of the features of objects.
6. Research analytical and comparative measurements of details in impressions/images/objects that take place by human examiners.
7. Research analytical and comparative measurements of details in impressions/images/objects that take place using technology or instruments.
8. Research judgments made from individual measurements.
9. Research validity and reliability of judgments and conclusions generated from those measurements.
10. Research patterns of features as they develop, over time and use. This would be within objects that have been generated by humans (such as random handwriting characteristics as a writer's ability matures with age or randomly acquired characteristics in shoe soles from new and throughout a sole's existence.
11. Research the consistency of conclusions reached among sets of trained examiners.
12. Research science of comparisons, as related to all disciplines and examiners.

Paul L Morrow - Forensic pathologist, Auckland, NZ, formerly Chief Medical Examiner, Vermont

It is important to recognize that forensic pathology is the practice of medicine and not classified as a "pattern–based forensic science". The foundational aspects of forensic pathology are those of the practice of medicine.

Eoghan Casey, Multiple titles and affiliations related to digital forensics and cyber investigation

I am responding to this questionnaire as an experienced forensic analyst and researcher of digital evidence. I am not responding as the Chief Scientist of the DoD Cyber Crime Center, or as the Executive Secretary of the NIST OSAC Digital/Multimedia Scientific Area Committee. There are many patterns in digital crime scenes, both direct (e.g., use of USB mass storage devices) and indirect (e.g., file allocation patterns). There have been a wide range of studies delving into various mechanisms and structures of digital traces and patterns, including peer reviewed research papers published in the Journal of Digital Investigation (http://www.journals.elsevier.com/digital-investigation/). Many of these studies support foundational

aspects of digital evidence analysis, and additional studies are needed as new technology emerges. Specifically, more scientific studies are needed to develop reliable methods to individualize using digital evidence, including recognizing people on the basis of patterns in data.

Digital and multimedia evidence is broad as an ocean, encompassing many kinds of criminal activities. A trip to kill a person, an electronic bank robbery, a terrorist attack can each have a digital nexus. Patterns in digital form can be found within each of these criminal acts: financial transactions, queries of online maps, electronic communications, geolocation data, and much more. Some of these traces are sufficiently distinctive to reveal the identity of the person behind the digital curtain. In the digital realm, there are analogs to fingerprints, toolmarks, verbal signatures, and other traditional pattern-based evidence. In this context, over the past 15 years through the DFRWS conference and proceedings, various studies have been presented and published that demonstrate the reliability and validity of digital forensic methods. In forming the DFRWS response to the above question, members of the Board of Directors and the Organizing Committees determined that narrowly focusing on papers published in the past five years would miss very important works that support foundational aspects of digital forensics. Therefore, it was decided not to list specific papers as part of this response. All papers published by DFRWS are freely available on the conference website (www.dfrws.org).

As for the second part of this question, there is an ongoing effort in digital forensics to develop methods and processes to deal with each new technology as a source of digital evidence. Studies are needed to establish the reliability and validity of these digital forensic methods and processes. DFRWS contributes to these ongoing efforts by attempting to address the needs of coming years, concentrating on new technology and refining existing digital forensic methods and processes.

Michele Catellier, MD, Associate Medical Examiner, State of Iowa

As a forensic pathologist (medical doctor) these are areas related to crime labs. Thus, this is not specifically related to my area of expertise.

Professor Sue Black and Professor Niamh NicDaeid, Professors at CAHID, University of Dundee, UK

A literature search across the named evidence types has revealed little foundational research which addresses the comparative problem relating to feature mapping across the relevant forensic evidence types outside of fingerprint comparison. Here a number of impactful reports/papers stand out and describe both the nature of the challenge as well as a potential foundation for the future.

The first is the Fingerprint Inquiry Report, published by Scottish Government in December 2011 which recommended that fingerprint evidence should be recognised as opinion evidence, not fact, and those involved in the criminal justice system need to assess it as such on its merits.

Secondly, Ulery BT et al (2012) Repeatability and Reproducibility of Decisions by Latent Fingerprint Examiners. PLoS ONE 7(3): e32800, which explores the challenges with decision making across examiners, why opposing decisions were observed and why an objective assessment mechanism is desirable.

Thirdly, C. Neumann et al, (2012) Quantifying the weight of evidence from a forensic fingerprint comparison: a new paradigm, Journal of the Royal Statistical Society: Series A (Statistics in Society) Volume 175, Issue 2, pages 371–415, which explores alternative mathematical models for the assessment and comparison of fingerprints outside of a likelihood ratio approach or that a numerical standard.

A range of publications have continued to address the comparison challenge for fingerprints and include work by Neumann, Champod and Langenburg amongst others in both identifying the challenges and highlighting possible solutions. Amongst these, various approaches were advocated.

Comparison research that examines patterns of anatomical features between offender and suspect images have been published from an anatomical database. Black et al. (2014). The incidence of scarring on the dorsum of the hand. Int J Led Med 128 (3): 545-553. Jackson and Black (2014). Use of data to inform expert evaluative opinion in the comparison of hand images – the importance of scars. Int J Leg Med 128: 555-563. Black et al. (2014). The incidence and position of melanocytic nevi for the purposes of forensic image comparison. Int J Leg Med. 128: 535-543.

Comparative studies for other impression evidence (firearms/toolmarks/shoeprints/tireprints) are variable and tend to concentrate on defining and comparing class characteristics on the basis of a 'match - no match' criteria rather than devising and developing core mathematical techniques to landscape the data obtained from impressions and explore more deeply how these landscapes can then be exploited using multivariate analysis to develop appropriate matching algorithms with associated error and measurement uncertainties. This approach is developing well in other areas of relevant forensic data analysis and in particular with the analysis of patterns in ignitable liquids and chemical drug profiles (L. A. McGregor et al (2012). Multivariate statistical methods for the classification of coal tars from former manufactured gas plants Envir Sci and Tech, 46,7: 3744-3752. H A. S. Buchanan et al, (2011). Organic Impurities, Stable Isotopes, or Both: A Comparison of Instrumental and Pattern Recognition Techniques for the Profiling of MDMA, Anal methods, 3,10: 2279-2288. W N.S Mat-Desa et al,(2011). Classification and source determination of Medium Petroleum Distillates by Chemometric and Artificial Neural Network: The Self Organising Feature Approach. Anal Chem, 83, 20: 7745-7754)

The studies required are those which will develop appropriate ground truth databases of sufficient size such that the repeatability, reproducibility and situational variations within the generated data can be assessed with true mathematical rigor. From this, an assessment can be made as to whether it is even possible to create appropriate pattern matching algorithms for specific evidence types and an exploration of the boundaries of these algorithms, their strengths and weaknesses can be exposed and decisions follow as to their reliability for use as evidence in criminal proceedings.

Michele Triplett, Forensic Operations Manager-King County Regional AFIS

Methodology The current method for arriving at pattern evidence conclusions is to do a visual comparison. The standard for how much information is enough to arrive at a conclusion is at the discretion of each practitioner, dependent on their own comfort level, making conclusions personal opinions not necessarily scientific conclusions. It is not possible to validate a personal opinion, therefore researchers focus on the accuracy of opinions, distracting from the fact that a method is nonexistent. Some disciplines state that ACE-V is the current method however, as noted by the NAS report, ACE-V is not a method, it is the acronym for the words/steps to describe decision making (analyze, compare, evaluate and have conclusion verified). These four steps are performed differently by everyone; ACE-V lacks any specifics to be considered a method.

Goal: Accuracy vs Well Supported Prior to developing a method for arriving at conclusions, the goal needs to be stated. Many people state that the goal is to get an accurate conclusion, which again focuses on the conclusion and distracts from the fact that there is not a stated method. Accuracy is an unachievable goal without a means of measuring accuracy (i.e., the ground truth is never known in casework). Currently accuracy is measured by having a conclusion verified. However, verification is a measure of concurrence, not

accuracy. When the goal is unachievable, researchers flounder in developing a method to achieve the goal. There is a misconception that frequency distributions will lead to accurate conclusions. Frequency distributions can achieve fairly accurate results when frequency distributions are constant, as with DNA, but frequency distributions are not constant for other pattern evidence disciplines. This is why they have not been used in the past. The only achievable goal for non-quantifiable conclusions, i.e., deductive logic, is to ensure that each conclusion is well supported and holds up to intense scrutiny, similar to how the research into global warming is assessed.

Reliability Studies Reliability studies have focused on overall error rates, regardless of the method, and have not looked into the risk of error in a specific case. Methods need to be clearly defined so that the risk of error in each case can to be determined. This can be accomplished by assessing the ambiguity of the data being used to arrive at the conclusion. The attached paper, scheduled to be published in Jan. 2016, proposes a goal and a method which assesses the risk of error for each conclusion regardless of the discipline.

Xhemajl Ademaj, Fellow American Academy of Forensic Science, Kosovo

Mostly are necessary scientific publications that have basis to scientific research based on Forensic Laboratory practice.

Michael T. Beddow, Forensic Scientist IV, Phoenix Police Department Crime Laboratory

Even though several different fields within Forensic Science fall under the general category of "pattern-based forensic science methods" they are each unique and independent fields: this independence is solely based upon their subject matter. It is not relevant or prudent to compare and contrast "pattern based forensic science methods" such as latent print analysis and firearm/toolmark examination when their subject matter is so completely different: the analysis of friction ridge detail on human tissue versus the analysis of microscope imperfections and defects within mechanically created toolmarks. Thus it is very essential that each "pattern based forensic science method" be reviewed and substantiated individually, and not as one general category. Therefore the following documentation will only be related to that of Forensic Firearm and Toolmark Examination as that is my field of expertise.

The field of Forensic Firearm and Toolmark Examination has existed in the mainstream law enforcement and criminal justice systems around the world for over a century. The field began with the manual comparison of individually captured photomicrographs in the early 20th century. It has progressed to the use of modern digital imaging systems coupled with precision microscopy equipment. Further advances into laser scanning 3D surface topography systems and confocal microscopy show promise as the direction of the future. Regardless of the era and type of equipment that has been or is being utilized, the foundational aspects of Forensic Firearm and Toolmark Examination has gone unchanged: the evaluation and comparison of the unique surface contours of two toolmarks with the intent of developing an opinion as to whether or not they were produced by a common or separate tool(s).

Scientists within this field, academia and governmental organizations such as the National Institute of Standards and Technology (NIST) are constantly striving to further support the methods and foundations of our science through continued research. Below is a list of relevant studies that have been published in the peer reviewed Association of Firearm and Toolmark Examiners (AFTE) journal. See research papers referenced – they include topics that involve consecutively manufactured firearm components and tools, toolmark longevity, subclass characteristics, comparison error rates, toolmark 3D surface imaging, amongst others.

At present, and within the foreseeable future, the type of research that needs to be conducted to continue to demonstrate the reliability and validity of Forensic Firearm and Toolmark Examination is as follows:

- Continue investigations into new machining and manufacturing methods utilized in the manufacture of firearms and other tools.
- Research into new technologies such as current projects looking into 3D laser scanning surface topography systems and confocal microscopy systems

This combination of research ideas will allow for the technological advancement of the tools available to Forensic Firearms Examiners while at the same time continuing to strengthen the basis for which our theories of identification are based upon. While research assistance from all sources (academia, government, etc.) are extremely beneficial it is ultimately important, that at a minimum, a competent Forensic Firearms Examiner is in some way associated with the work even if only in an advisory role.

Melissa Gische, Chair, OSAC Friction Ridge Subcommittee

There are a number of reports and publications that may be cited when describing the volume of literature related to friction ridge examinations. The Organization of Scientific Area Committees (OSAC) Friction Ridge Subcommittee (FRS) Research Task Group is currently drafting an updated document detailing existing research, as well as research needs. Until this draft has undergone the appropriate OSAC approval process for release, the following two references provide a good overview of the existing literature in the field.

1. Scientific Working Group on Friction Ridge Analysis, Study and Technology (SWGFAST) Response to The Research, Development, Testing and Evaluation Inter-Agency Working Group (RDT&E IWG) of the National Science and Technology Council, Committee on Science, Subcommittee on Forensic Science http://swgfast.org/Resources/111117-ReplytoRDT&E-FINAL.pdf
2. Fingermarks and other Impressions Review 2010 – 2013 published in association with the 17th Interpol International Forensic Science Managers Symposium http://www.interpol.int/content/download/21910/206602/version/1/file/IFSMSReviewPapers2013.pdf

Andy Smith, Chair - Firearm/Toolmark Subcommittee NIST OSAC

See literature citations for studies published in the past five years that provide foundational support to the discipline of firearm and toolmark comparison. Although these citations respond specifically to this Council's focus within the last five (5) years, it should be noted that a plethora of important literature has been generated outside this time constriction, which was reported in 2011 to the Research, Development, Testing and Evaluation subcommittee on Forensic Science Interagency Working Group (RDT&E IWG).

Scientific practice demands that possible exceptions be researched and published (efforts to test or falsify), and that a large body of confirmatory evidence from training programs, experimentation, etc., will forever remain unpublished.

It is the opinion of The Firearms/Toolmarks subcommittee of the Organization of Scientific Area Committees (OSAC) that the profession and science of firearm and toolmark comparison rests on a solid scientific foundation. The citations below represent a minor selection from a much larger body of work that encompases nearly a century of research and experiential knowledge. Despite this confidence, the professional community continues to perform new research and welcomes the scientific method of vigilant and rigorous testing of the underlying principles of the discipline. New studies using three dimensional measurement instruments and comparison software have provided objective data that supports the range of conclusions used by the profession.

There are published papers and books examining the relative frequency of toolmark evidence (Question # 2 References, #'s 1-11). These studies concluded the chance of a coincidental match to be low, and that a high degree of similarity between two toolmarks provides a strong basis for a conclusion of common origin.

These studies remain theoretical in nature and are not applied to toolmark casework in the forensic laboratory. There are a large number of random and changing factors in tool (and firearm) manufacturing. Therefore the goal of producing a statistical model or mathematical equation that can accurately predict toolmark variance remains elusive. The marks used by toolmark examiners are random in nature, and thus establishing a probability model requires an empirical statistical approach. This is a stark contrast to DNA that uses a generative model (the Hardy-Weinberg equation). Despite these difficulties, scientists continue to research the concepts of frequency, probability, likelihood ratios and automated comparisons in field of toolmark identification (see Question 2 References, #'s 12-28).

NIST in collaboration with the FBI and crime labs across the U.S. is currently compiling a database of known test fired bullets and cartridge cases, and will be the curator of this set of reference samples. The purpose of the database, as outlined by NIST at http://www.nist.gov/forensics/ballisticsdb/, is to foster the development and validation of measurement methods, algorithms, metrics, and quantitative confidence limits for objective firearm identification. Furthermore, the database is intended to improve the scientific knowledge base on the similarity of marks from different firearms and the variability of marks from the same firearm, and ease the transition to the application of three-dimensional surface topography data in firearms identification. This database will serve as a useful set upon which different search and analysis software can be compared.

Additionally, the lack of frequency data or the ability to express an opinion as a likelihood ratio does not automatically lessen a scientific conclusion. Many of humankind's greatest scientific discoveries did not enjoy the benefit of a probability distribution but rather utilized detailed observations from clearly reasoned experimental design. It has historically been, and remains, a primary goal of the firearm and toolmark profession to support practitioners' conclusions with objective or statistical criteria. However, the fact that work remains does not make the current state of toolmark comparison bad science.

Clifford Spiegelman, Distinguished Professor Texas A&M U

None, there are only deeply flawed fractional studies that cannot be pieced together well by meta-analyses. See Law, Probability and Risk (2012) 0, 1–19 doi:10.1093/lpr/mgs028

Analysis of experiments in forensic firearms/toolmarks practice offered as support for low rates of practice error and claims of inferential certainty

Brandon Giroux, President, Association of Firearm and Tool Mark Examiners (AFTE)

Q1 Part 1: What studies have been published in the past 5 years that support the foundational aspects of each of the pattern-based forensic science methods, including (but not limited to) latent print analysis; firearms/toolmarks; shoe/tire prints; bitemark analysis; questioned documents?

The Scientific Working Group for Firearm and Toolmarks (SWGGUN) developed the Admissibility Resource Kit (ARK) in 2005 to assist forensic firearm and tool mark examiners in the preparation for evidence admissibility hearings. When the SWGGUN was defunded in 2013, the AFTE Board of Directors and the past SWGGUN members decided to republish and maintain the ARK on the AFTE website. The ARK contains a collection of resources that represents significant research, legal opinions, challenges, rulings and other issues related to the discipline. The foundational research included on the ARK extends well beyond the past 5 years.

Q1 Part 2: What studies are needed to demonstrate the reliability and validity of these methods? The reliability of the science of firearm and tool mark identification has been established through numerous

validation studies, most of which are cited on the AFTE website under the SWGGUN Admissibility Resource Kit (https://afte.org/resources/swggun-ark). These studies evaluate tools (such as firearms) produced using different manufacturing methods, and have consistently shown that qualified forensic practitioners are able to distinguish between tool marks produced using different tools. Additional validation studies may be appropriate to capture new manufacturing processes, as well as, responses from a larger segment of the forensic firearm and tool mark population.

Nelson Bunn, Director of Policy and Government Affairs, National District Attorneys Association

The pattern-based forensic science methods are used in court on a daily basis by prosecutors around the nation. In the last five years, many studies have been published in regards to the pattern-based science methods. One of the charges put forth by the National Institute of Science and Technology (NIST) is to provide research and reference data for the forensic science disciplines. Through the development of the Organization of Scientific Area Committees (OSAC) and with the augment of the Scientific Working Groups (SWGs), the OSAC's are in a position to develop and compile a list of studies to demonstrate the reliability and validity of these methods. Two examples of how the SWGs along with the OSACs should play a role in this are as follows: 1) The Scientific Working Group on Friction Ridge Analysis, Study and Technology (SWGFAST) website contains numerous sources containing bibliographies of literature supporting the friction ridge sciences. We are also attaching the 64-page response to a request from the Research, Development, Testing & Evaluation InterAgency Working Group of the National Science and Technology Council, Committee on Science, Subcommittee on Forensic Science asking for an annotated bibliography of the literature supporting the friction ridge sciences from 2011. Since then, there have been many more publications, as well as research supporting the friction ridge sciences. These can be found on the SWGFAST website as references throughout their documents 2) The Scientific Working Group for Firearms and Toolmarks (SWGGUN) also contain material that would be of interest on their website. The Foundations of Firearm and Toolmark Identification address the foundational aspect of the pattern-based forensic science method. Again from 2011, in response to questions posed by the Research, Development, Testing & Evaluation Inter-Agency Working Group of the National Science and Technology Council, Committee on Science, Subcommittee on Forensic Science, SWGGUN compiled a list of annotated bibliographies of the foundational research performed in the forensic firearms and tool marks discipline. The list is 47 pages in length, and can be found on the SWGGUN website. Accredited laboratories participate in competency and proficiency testing programs. Each analyst is competency tested before the start of casework while proficiency testing is conducted by each analyst on an annual basis. Analysts performing DNA analysis are proficiency tested twice a year. Blind proficiency testing is an additional test that has been discussed for many years. There are many publications that exist on the topic of blind proficiency testing. Unlike a medical laboratory, the crime laboratory receives evidence from a law enforcement agency. In order to have a truly blind proficiency, the law enforcement agency must also be included in the process, but most analysts are keen to the blind proficiency test program and will eventually determine the test is blind in nature. We must remind the members of PCAST, that the defense in any forensic case, has the ability to have the evidence reanalyzed and if the sample is to be consumed, the defense also has the ability to send a defense expert to witness the testing. Promising new scientific methods include the advent of Next Generation Sequencing for DNA, oral fluid analysis for toxicology, biometric growth in the form of iris, tattoos, face, etc. and ballistic imaging technology. Any new method should be properly validated using developmental validation, as well as site validation models. Standards of validity and reliability should follow the OSAC Standards or SWG Guidelines for validation. In addition, Daubert or Kelly Frye standards should be used to admit the new forensic methods in a court of law. NDAA wishes to be a partner in the PCAST model as it attempts to further forensic science in regards to research of forensic science methods, as well as addressing the validity and reliability of the forensic methods. Prosecutors around the nation bring a unique perspective to this endeavor and should be allowed a seat at the table.

American Academy of Forensic Sciences (AAFS) Board of Directors

Forensic Science is an ever evolving field due to continuing technological advances and the fortunate increase of knowledge in the use of the technology. Many studies have been conducted prior to the past five years, which have laid a solid foundation for the field as we continue to move forward. For example, an American Board of Forensic Odontology study over 15 years ago, which involved the distribution of models and photos to a large percentage of active board certified diplomates, is still being cited today, particularly by the critics of bitemark analysis.

Although it is difficult to create an exhaustive list of studies in the areas of interest, a focused list is provided here for questioned document examination: References provided

The lists mentioned above are far from complete. The inclusion of a particular study is not intended as an endorsement of the study or its results, nor is the exclusion of a study intended as a dismissal. The lists provided are only intended to show that work is being done, particularly in the two areas mentioned.

It may be possible for one to obtain a more comprehensive response to this question by contacting the Organization of Scientific Area Committees (OSAC). The organization is a collaborative body of more than 500 forensic science practitioners and other experts who represent local, state, and federal agencies; academia; and industry. OSAC, part of an initiative by the National Institute of Standards and Technology (NIST) and the Department of Justice, is comprised of five scientific area committees, three of which, based upon the sub-committees, may be of particular interest for this study:

Physics/ Pattern Interpretation
- Firearms & Toolmarks
- Footwear & Tire
- Forensic Document Examination
- Friction Ridge
- Bloodstain Pattern Analysis

Crime Scene Death/ Death Investigation
- Odontology
- Fire & Explosion Investigation

Chemistry/ Instrumental Analysis
- Fire Debris & Explosives
- Gunshot Residue

Jill Spriggs, President, CA Association of Crime Lab Directors

The Organization of Scientific Area Committee (OSAC) on Physics and Pattern Interpretation should be given time to formulate a comprehensive response to this question. We are sure that individual laboratories may be able to give partial lists of references, but the subcommittees on Friction Ridge Evidence, Forensic Document Examination, Footwear/Tire Marks and Firearms/Toolmarks should be able to give more comprehensive lists of studies supporting the foundational aspects of pattern-based forensic methods.

Randy A. Sandifer, Forensic Scientist, American Academy of Forensic Sciences

Strengthening the Forensic Sciences prepared by the National Science and Technology Council Committee on Science. Such journals emphasize the issues that plague forensic science with an overall theme of licensure as the cure all.

Consortium of Forensic Science Organizations

Challenges of a Forensic Science Literature Search: At your request we did circulate the survey to our membership. However, the task to respond is a daunting one. The sheer number of journals and articles produced in the forensic science space each year is overwhelming. Appendix A of this document is a list of many of the forensic science journals regularly publishing forensic science research. We tried to provide some type of helpful review of available literature, but this effort proved unfruitful. We did learn through this effort some things that may benefit the PCAST effort:

- There is currently no available search engine available to forensic practitioners that contains the majority of forensic science journals.
- Even if a search engine existed to catalog all the research, there are thousands of search terms that could be used to bring up different articles related to these disciplines.
- The majority of forensic practitioners do not have access to the majority of the forensic science journals and research articles.
- There are very few forensic science librarians and scant resources in the forensic science community to perform comprehensive literature searches.
- A great deal of the research has been done outside of the United States and in foreign language journals without translation resources.
- Much of the forensic science research is not published or not published in a cataloged way.

Conducting a comprehensive literature search contains many obstacles for the forensic science practitioner. As noted above, there is no single source, whether database or search engine, that provides complete indexing to the forensic science literature. While a database such as PubMed, from the National Library of Medicine, provides access to a respectable number of forensic science journals, there are glaring omissions. The AFTE Journal, from the Association of Firearms and Toolmark Examiners, is the preeminent journal in its field, but it is not indexed either in PubMed or in a scientific/scholarly search engine such as Google Scholar. The Journal of Forensic Identification, another core forensic science journal, can only be searched via a costly commercial subscription database. A literature search can not only take many hours out of a busy bench scientist's day, but some of the core information might be completely inaccessible. The very few labs that have librarian resources are overwhelmed with requests from practitioners that do not have access to these services.

Another significant challenge to providing a literature search is the number of "non-forensic science specific journals" publishing in the forensic science arena. For example, a simple search related to the PCAST survey brought up two pages of references from "non-forensic science" medical and legal journals that we have not listed in Appendix A of this document.

CFSO made a proposal to the Department of Justice for a forensic science library service that would start to put together the available research and catalog it for searching by the community. PCAST supporting a forensic library service to include the development of a forensic literature search tool, and recommending this to the President could be immediately impactful on the forensic community.

Matt Johnson, Orange County Sheriff's Department, OSAC Footwear/Tire Track Subcommittee

Hancock et. al. (2012) collected 500 footwear impressions from participants at the University of Auckland, New Zealand. Every print was compared to all others in order to determine associations of class characteristics within the dataset, for a total of 124,750 pairwise comparisons. In addition, a subset of impressions was selected to be used as partial prints in order to mimic the types of evidence typically encountered at a crime scene. Of the 500 prints collected, approximately 97% of the outsole patterns were only encountered once in the dataset and the maximum number of repeated patterns was just 3 [1]. For

the partial prints, approximately 94% of the dataset was considered unique, with no duplicate manufacturing patterns [1]. The results from this study suggest that an assessment of class characteristics is integral to narrowing down the possible suspect shoes which could have created an impression.

Likewise, Gross et. al. (2013) analyzed a set of 402 impressions, obtained from the casework of the Minnesota Bureau of Criminal Apprehension, for class correspondences. Similar to Hancock et. al. (2012), pairwise comparisons were conducted for a total of 80,601 possible pairs. Comparisons were conducted using the following four-tired hierarchy of analysis [2]:

1. Examine outsoles for the presence of nine outsole elements.
2. Evaluate pairs for consistency in general outsole design.
3. Assess the correspondence of design element shape, size, number, and position.
4. Compare wear patterns on outsoles.

This methodology was used in a stepwise manner. More specifically, if outsoles exhibited discordancy at any point in this chain, the impressions were distinguished and examination was concluded without any further comparison. Based on the results of this study, 99% of all impressions were distinguishable without considering wear on the outsole; only two impressions required an analysis of erosion in order to be differentiated [2]. The findings from this study are consistent with previous findings that manufacturing characteristics are extremely effective at minimizing the number of possible source shoes.

Though class and subclass characteristics are immensely useful for discriminating purposes, these features cannot be used to reach an identification. Rather, an analysis of randomly acquired characteristics (RACs) is necessary in order to determine whether a given shoe was the source of a crime scene print. In recent years, several studies have examined the discriminating power of RACs and determined that these features are, in fact, random and unique enough to be considered identifying and that this discrimination potential is persistent even with continued wear [4, 5, 6].

Wilson (2012) examined the outsoles of 39 pairs of the same shoe which were worn by the same person over a comparable number of miles. This scenario, in theory, maximizes the potential for random co-occurrence of features on different outsoles because conditions (type of shoe, wearer, and degree of wear) were kept as constant as possible. Randomly acquired characteristics on each outsole were identified, marked, and counted. After comparison between shoes, even in outsoles that exhibited a comparable *number* of features, the two were easily distinguished based on a visual assessment of the location, size, and shape of RACs present [4]. Therefore, these results indicate that accidental characteristics are random and can provide sufficient discrimination potential to be used for an identification of source.

While Wilson (2012) offers evidence that accidental characteristics are highly discriminating and can be utilized for footwear identification, a major challenge with footwear impression evidence is continued wear after the commission of a crime. Just as RACs are acquired by wear, they can likewise be worn away over time due to continued wear of the outsoles. Therefore, a major factor contributing to the weight of this evidence is the timeline; however, research suggests that even with additional wear an identification of source can still be accurately made. Petraco et. al. (2010) examined footwear impressions using principal component analysis (PCA), a technique commonly utilized for facial recognition. Assuming that variance captures the information of the dataset, PCA can ideally be used to reduce the data by minimizing the number of correlated features while still capturing the variability of the original dataset [7]. Therefore, a dataset is represented as a number of principal components, which comprise the minimum number of features required to retain much of the original information contained in a dataset. For this study, five pairs

of the same type of shoe, each worn by the same individual, were examined. More specifically, the RACs present in the ball of the outsole were identified and analyzed based on position, using an Abbott Grid locator. After localization, PCA was completed on the dataset. Similarity between the resulting principal components was computed and the results indicated that the correct identification rate of the five pairs of shoes was approximately 92% [5]. These results indicate that with wear, even when the shoes are worn by the same person and exhibit the same manufacturing characteristics, shoe impressions are still statistically separable and the RACs provide enough information to be used for identification.

Furthermore, Sheets et. al. (2013) utilized PCA to determine the rate at which wear affects the persistence of acquired characteristics. A set of "accidentals", each of relatively the same size and location, was cut into each shoe in a set of eleven pairs. Participants then wore each pair for a period of seven weeks and the outsoles were examined several times throughout the period of wear [6]. By overlaying a square grid onto each outsole, the size of each accidental, based upon percentage of the grid occupied, was recorded; location and shape of features were ignored for these analyses. Throughout the study, intra-shoe variation was much lower than inter-shoe variation; thus, even with additional wear, each shoe better matched itself than any other shoe to which it was compared [6].

Therefore, recent research provides support for the utility and discriminating potential of footwear impression evidence through analysis of both manufacturing and acquired characteristics and provides evidence, both empirical and theoretical, for the identification of source based upon an analysis of randomly acquired characteristics on shoe outsoles [1, 2, 4-6]. Furthermore, some of these studies propose mathematical methods for comparison of RACs [5, 6]. The results from these studies further support the foundational assertion that features on outsoles can be used to greatly reduce a suspect pool of shoes and even further, that accidental characteristics can be used for identification of footwear.

Works Cited

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(3) SWGTREAD, 03 2006. [Online]. Available: http://www.swgtread.org/images/documents/standards/published/swgtread_08_examination_200603.pdf. [Accessed 04 12 2015].
(4) H. D. Wilson, "Comparison of individual characteristics in the outsoles of thirty-nine pairs of Adidas Supernova Classic shoes," *Journal of Forensic Identification,* vol. 62, no. 3, pp. 194-203, 2012.
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Question 2 – Baseline frequencies and databases

Have studies been conducted to establish baseline frequencies of characteristics or features used in these pattern-based matching techniques? If not, how might such studies be conducted? What publicly accessible databases exist that could support such studies? What closed databases exist? Where such databases exist, how are they controlled and curated? If studies have not been conducted, what conclusions can and cannot be stated about the relationship between the crime scene evidence and a known suspect or tool (e.g., firearm)?

Itiel Dror, Senior Cognitive Neuroscience Researcher, University College of London

The problem is that baseline frequencies of characteristics in the pattern are a subjective perceptual issue (see answer to Question 1, above). Forensic examiners are not only inconsistent with one another about what characteristics are in the evidence, but they are inconsistent with themselves at Time 1 and Time 2 (see paper 1, attached).

Stephen E. Fienberg, Maurice Falk University Professor of Statistics and Social Science, Carnegie Mellon University

The one domain where baseline data might be made available is in fingerprint comparisons , but the only public data available are from highly stylized studies and comparisons carried out via NIST and its sponsored competitions, and these tell us little of value what it comes to matching partial latents form crime scenes.

Steven Johnson, Board Chair - The International Association for Identification

Additional research into probability modeling as well as baselines for secondary and tertiary friction ridge features would be welcome by the latent print examination community. There are a number of academics that are pursuing the probability models for latent print examination to establish levels of confidence in results.

C. Michael Bowers, Odontologist, Ventura Medical Examiner

Bitemark pattern advocates continue to ignore or avoid being transparent in the media about human dentition relevant to biting (i.e. front teeth) not being analagous to a "fingerprint." I recently heard testimony, from the ongoing Texas Forensic Sci Commission, from David Senn, the lead bitemark advocate, that dental "uniqueness" has been proven by just one published article. Misleading and fraudulent statements are unethical, and should have consequences. Sadly, the American Academy of Forensic Sciences is not following its own mission statement regarding forensic "reform" and scientific advancement.

Joe Cecil, Senior Research Associate, Division of Research, Federal Judicial Center

Such studies have not to my knowledge been conducted, at least on samples at they appear at a crime scene. In the absence of such studies, the testifying expert can only testify to similarities in the evidence sample and suspect sample. No statistical estimates of the likelihood of a match are appropriate.

Frederick R. Bieber, Professor, Harvard Medical School

Most ballasticians and other tool-mark examiners, when asked, state that the basis for their conclusions is "experience". Very few databases exist and they could be established by academic and government labs and shared with the forensic community.

Ahmed, PhD genetic engineering /DNA fingerprint

HLA class I and II molecules in type 2 diabetic Iraqi patient's .Book. Verlag/publisher Scholar press .2105.ISBN:978-3-639-76681-3.

Mary Beth Hauptle, Forensic Odontologist, FCMEO

No. In my opinion skin is a medium which will never register tooth impressions of sufficient quality to render an opinion as to who was the biter.

Melissa Connor, Director, Forensic Investigation Research Station

There has been a lot of work done since the NAS 2009 report. It needs to be collected, collated, and summarized.

Tatiana Maria Blanco Alvarez, MA, Graduate student TTU

As far as I know there aren't studies that established baselines, because these techniques tend to be more empirical. But one way to do one might be to established an specific protocol on how to take sample and how to analyses them, and them use the same protocol with multicultural samples and in different countries in order to provide support on the protocol. To support this protocol, one can find research in databases as PsycInfo, PubMed, Science Direct, EBSCO Host, as well as different Journals from Universities or Faculties. But it's important that whatever Journal used, it should be peer reviewed and a high impact, that means that it's articles are cited more often than others. Given this lack of information, is important to state the level of accuracy of the method, mention where this method comes from, and never say that it's a 100% certainty of the evidence, because there is always a percentage or margin of error.

Femblix Meek Tom Jr, Student Citizencorps.gov AAFS.ORG Fvtc.edu Dna.gov Wvu.edu Bronx Community College

Strengthening Forensic Science in the United States: A Path Forward (2009)
Chapter: 4 The Principles of Science and Interpreting Scientific Data

Heather Garvin, Assistant Prof of Anthropology/Applied Forensic Sciences, Mercyhurst University, Erie, PA

In short - Yes. Again, this is a poorly worded question for a survey - there are too many aspects to consider. In Forensic Anthropology there are some available databases - for example, the Forensic Database, NAMUS, and even radiographic databases (e.g., PATRICIA). Museum collections are available for comparative research. With technological improvements, scientists are working to make more data readily available online.

Pierre Margot, Emeritus Professor, University Lausanne

Many studies have been conducted over the last 25 years. Often using controlled databases (highlighted in the above publications (quest. 1)).
The work of professor Christophe Champod started with very elaborate statistical studies in fingerprint already 20 years ago (PhD thesis in 1996!)

Mark Leney, Professor, UMass Medical School and Deputy Director, MassBiologics

No. Apparently not. Reference collections of human remains generally are hard to accumulate, have idiosyncrasies and are fraught with ethical issues. There is a special problem when the reference set is biological materials - easier when it is a clinical sample such as a blood or tissue sample but much harder where hard tissues need to be referenced. There is no such reference database of material accessible in the US. A collaboration between anatomy schools and the forensic sciences might provide something like a population sample of cadavers with known medical histories and causes of death as a reference populations. The retention of physical remains is an ethical issue to be resolved but might be remedied to some extent by the storage of standardized high resolution 3D digital images.

Eric Warren, Ph.D., Special Agent/Forensic Scientist, Tennessee Bureau of Investigation

Yes, studies have been performed as far back as the 1950s, however, only selected studies within the past 10 years are cited below. To my knowledge, there are no far-reaching, publicly accessible databases. There are private databases such as the database controlled and maintained by the ATF, administered by Ultra Technologies (FTI).

Robert Gaensslen, Prof Emeritus, Univ of Illinois Chicago

I would say Yes with fingerprints, because of AFIS and fingerprint-based ID systems (such as global entry). The big AFIS databases are not public and not really available to researchers. They are held in check by law enforcement, mainly the FBI.

There are some firearms databases (NIBIN), but it is clear that these algorithms break down as the size of the data base grows, ie you get a lot of false hits.

Maybe the way to go at the problem is to have computers sort through large databases, varying parameters, and then being able to estimate probabilities of chance duplication. Examiners can then state that the marks (whatever they are) appear to be the same, and that controlled studies show such-and-such a rate of chance duplication. A lot along the lines of DNA match reporting. Pattern evidence examiners hate this idea, but it is probably the way to go, and would be honest. It is not totally clear how you would do controlled studies on large numbers of tire track, footwear, & bitemark, items. You have to come to some agreement on what a 'feature' is. Then you have to arrange for a pattern recognition software pkge to be able to get the marks into register and count the features.

Dr. Sushil Kumar Sharma, Editor, EC Chemistry, UK

1. Cross-correlation Based Algorithm for Fingerprint recognition Using MATLAB Miss.Arti Sandbhor, Miss.Krutika Deshpande, Prof. S.S.Jahagirdar

International Journal of Engineering and Technical Research (IJETR) ISSN: 2321-0869, Volume-2, Issue-3, March 2014

Abstract— This paper is a study and implementation of a correlation-based fingerprint recognition algorithm which is based on pixel values of images. This algorithm directly uses the gray-scale information of the fingerprints. The correlation-based fingerprint algorithm selects template, Pixel values of template is correlate with pixel values of all N number of images in existing database and looks for the maximum value in correlated data which is greater than some threshold value. Maximum value among correlated data gives the appropriate match of template from existing images in database. This paper involves implementation of cross-correlation based algorithm using MATLAB.

2. FINGERPRINT MATCHING BASED ON STATISTICAL TEXTURE FEATURES.

IJCSMC, Vol. 3, Issue. 9, September 2014, pg.34 – 41.

Abstract: Fingerprint is a reliable biometric which is used for personal verification. Three arithmetical features are extracted from fingerprint images and represented using a mathematical reproduction. These features are (1) an entropy coefficient, computed from the intensity histogram of the image, (2) a relationship coefficient, computed by correlation operation between the novel image and a filtered version of the image obtained using a 2D wiener filter, and (3) an energy coefficient, obtained by first subjecting the image to a 5-level wavelet decomposition and thereafter computing the proportion energy of the approximation coefficient obtained after the 5th level decomposition. Results show that fingerprint texture feature can be convincingly used for discrimination and for personal verification.

3. A Novel Pattern Matching Approach for Fingerprint-based Authentication ... fingerprintmatching technique, which matches the fingerprint information by 1, 2014, pp. 62–71. [7] K. H. Q. Zhang and H. Yan, “Fingerprint classification based on.

Moses S Schanfield, Professor, Department of Forensic Science, George Washington University

If you are going to have databases, or research bases they need to be publicly available, curated and of a standardized basis, so all studies become additive, and not a bunch of anecdotal data collection as currently exists. In the past we had curated biological collections controlled by CDC and WHO. Data had to be returned to the controlling agency. Similar collections need to be collected once and then distributed to people doing research in the field, much as the HAPMAP and 1000 Genome Projects in human genetics.

Rigo Vargas, Professor, QD Section Chief, MS Forensic Laboratory

Yes.

See references.

What closed databases exist? “Frequency Occurrence of Handwriting and Hand-Printing Characteristics” database.

Where such databases exist, how are they controlled and curated? In the form of two Microsoft Access Spreadsheets, one for cursive writing and one for printed writing. The spreadsheets are in the possession of Tom Vastrick, Ellen Schuetzner, Heather Burske, Mark Johnson, and Michele Boulanger.

Michael Kusluski, Forensic Scientist, Michigan State Police

I don't see that this question would be part of a survey. It seems like you simply need to conduct more thorough research. Try searching in the AFTE Journal, The Journal of Forensic Identification and the like.

Dr. L. Thomas Johnson, Professor (Retired) Marquete University

Replication of Known Dental Characteristics in Porcine Skin:
Emerging Technologies for the Imaging Specialist
NIJ 2010-DN-BX-K176
Award period October 1, 2010 – September 30, 2013 4
Johnson, LT1; Radmer, TW1; Jeutter, DC3; Corliss, GF3; Stafford, GL1; Wirtz, TS1; 5
Groffy, RL4; Thulin, JD2; Ahn, KW2; Visotky, AD2 6
Abstract
This research project was proposed to study whether it is possible to replicate the patterns 9 of human teeth (bite marks) in porcine skin, be able to scientifically analyze any of these 10 patterns and correlate the pattern with a degree of probability to members of our established 11 population data set. 12
The null hypothesis states: It is not possible to replicate bite mark patterns in porcine 13 skin, nor can these bite mark patterns be scientifically correlated to a known population 14 data set with any degree of probability. 15 Bite marks were produced on twenty-five pigs with a bite pattern replication device using 50 16 sets of models of blinded dentitions. The models were selected randomly from a previously 17 quantified data set of 469. Prototyped dental models were mounted on a semi-automated 18 mechanical device which records the model number, physical location on the pig where the 19 force applied and the duration it was applied. Four patterns were created on each side of 20 twenty-five anesthetized pigs in predetermined areas. These sites were tested previously in a 21 pilot study; notably the hind quarter, abdomen, thorax and fore limb. Digital photographs of the 22 patterned injuries (bite marks) were exposed following the guidelines of the Scientific Working 23 Group on Imaging Technology (SWGIT) and the American Board of Forensic Odontology.(ABFO).

Two hundred images of each dental arch were selected from the eight hundred 25 photographs taken during the laboratory sessions and analyzed biometrically using a previously 26 validated software program.

Images were categorized as complete, partially complete or 27 unusable, based on the presence, partial presence or absence of the six anterior teeth in each 28 arch. Intersecting angles, the widths of the lateral and central incisors and the arch width 29 measured on the scaled images of the unknown models. The images were analyzed 30 independently by two investigators. Their measurements were then statistically compared to 31 an established population data set of 469 males, ages 18 to 44 years. Statistical analysis was 32 achieved using two models; Pearson's correlations and distance metric analysis. Pearson's 33 correlation results based on width only, angle only and widths plus angles were reported by 34 each investigator. Angles measured along with widths and compared to the known data set 35 ranked each set of models from 1 to 469 with a ranking of one showing the lowest p values. 36 Investigator #1 ranked 5 out of 143 images as number 1, 10 out of 143 in the top 1%, 34 out of 37 143 in the top 5% and 59 out of 143 in the top 10 %. Investigator #2 ranked 2 out of 156 as 38 number 1, 13 out of156 in the top 1%, 36 out of156 in the top 5% and 54 out of 156 in the top 39 10%. The second statistical model using distance metric analysis had a sample count of 102 40 images with 3 out of 102 within 1% of the population, 16 out of 102 within 5% of the population 41 and 23 out of 102 within 10% of the population when evaluating the results of the upper jaw only 42 from investigator #1. The concept of using an incisal line is based on geometric principles of line 43 segments and the angles they form when extended. The use of this concept will aid the crime laboratory imaging specialist and forensic odontologist in their analysis of bite marks (patterned injuries}. MeSH terms; forensic odontology, bite mark, dental characteristics, bite force, incisal line, quantification of dental characteristics, statistical analysis, load.

Howard A. Harris, Professor Emeritus

Dozens in each major area such as fingerprints, firearms I.D., Questioned Document Examination; shoe print, etc. Afis; Nybin; paint, shoe pattern etc.

Dr Geoffrey Stewart Morrison, Independent Forensic Consultant; Adjunct Associate Professor, Department of Linguistics, University of Alberta

My interpretation of this question is that it is asking about the availability of data for training statistical models which calculate the denominator of the likelihood ratio – see in the answer to Question 1 the discussion of the likelihood ratio framework, and the use of relevant data, quantitative measurements and statistical models. See also the papers referenced in my response to Question 1, which include studies which make such calculations.

At present, lack of suitable data is the biggest practical impediment to performing forensic voice comparison casework. Technical recording conditions (noise, communication system transmission, etc.) can potentially be simulated if one has a database of high-quality audio recordings, but the relevant population and the speaking styles cannot be simulated. Morrison, Rose, Zhang (2012) described a protocol for data collection which elicits natural speech in three different speaking styles which are common in forensic casework – telephone conversation, information exchange over the telephone, and simulated police interview. This protocol was used to collect a database of multi-session (non-contemporaneous) audio recordings of 500+ Australian English speakers (Morrison et al, 2015). The database is available to researchers and forensic practitioners upon request. It allows casework to be conducted when the relevant population is either male or female Australian English speakers and when the speaking styles in the recordings of the known and questioned speakers are similar to those included in the database, but not if the population or speaking styles differ. Few, or no, other existing databases fulfill the criteria necessary to conduct general casework of being reasonably large, and of having multiple high-quality non-contemporaneous recordings of each speaker in speaking styles common in forensic casework. To the best of my knowledge no database exists that would be generally suitable for performing casework involving US English. Although it is theoretically practical to collect databases of some populations and speaking styles in anticipation of performing casework and such databases may allow a relatively large proportion of cases to

be conducted, there will always be populations and conditions which cannot be anticipated or for which it is not an efficient use of resources to collect databases on the off chance that such cases will occur. If the case is important enough and the voice evidence important enough in the case, then resources may be available to collect relevant data on an as-needed basis. In practice there are few cases in which such case-specific data collection is performed. If relevant data are not available and not collected, then a proper forensic voice comparison cannot be conducted. Even if one had a method (e.g., a subjective judgment approach) which did not require training data, data for empirical testing would still be required and those data would have to be sufficiently representative of the relevant population and sufficiently reflective of the conditions of the known and questioned speaker recordings in the case. See references.

Josep De Alcaraz-Fossoul, Researcher and Assistant Professor, University of Barcelona

Q2-2: What publicly accessible databases exist that could support such studies? What closed databases exist? Where such databases exist, how are they controlled and curated?

One of the basic and powerful tools for solving crimes is the use of databases for the classification, search and comparison of evidence. There are many accessible databases available for law enforcement (mostly closed) specific for each discipline.

For fingerprints there are several different versions of Automated Fingerprint Identification Systems (AFIS) which usually work with comparable algorithms allowing easy transfer of data between them. Internationally they can or cannot be comparable. These databases are maintained and powered by law enforcement agencies worldwide and are subject to the highest and most rigorous confidentiality and privacy controls.

For firearms/toolmarks there exists the National Integrated Ballistic Information Network (NIBIN) which is an emerging system currently under the auspices of the Bureau of Alcohol, Tobacco, Firearms and Explosives of the US. Participating law enforcement agencies from around the world use Integrated Ballistic Identification Systems (IBIS) to obtain digital images of markings from ammunition recovered from crime scenes or a crime weapon test fires. These images can then be compared to link crime scenes or to link firearms to specific scenes. Other countries use similar databases based on same comparison principles. These databases are maintained and fed by law enforcement agencies.

For shoe/tire prints there is a diverse array of databases depending on the agency. For example, an open source collection of shoes (sneakerpedia.com) offer a large selection of items based on type, brand, and material, including a search engine. SOLEMATER and SICAR6R (provided by foster+freeman) are used for shoeprint 'pattern coding' to characterize a shoe print. They allow to link crimes to suspects or crimes to other crimes and share data across the network. EverASM™ software, provided by EVIDENT, allows high speed accurate footwear impression recognition and matching capabilities. In this case, crime scene shoe impressions may be entered to determine the manufacturer and model of shoe or compared to a database of existing suspects.

For tires, TreadMate™ is a commercial software that uses four parameters—pattern, size, damage, and wear— to identify individual impressions from vehicle tires and tire tread patterns, including manufacturer, date of market release, pictorial image, and pattern features (provided by foster+freeman). Other databases include Tirelibrary c which is a search engine that offers detailed information about thousands of tire makes, models, and sizes, among other details (provided by E-Solution Professionals).

For bitemark analysis I am unaware of the latest advancements in databases as this discipline escapes my field of expertise. I do not rule out some databases are currently in use.

For questioned documents analysis there are several databases available. For example, the Document Information System for Civil Status (DISCS) and EdisonTD are reference document databases with proficient descriptions of details in real ID documents that contain information about identity. EdisonTD has an open source version of the website with information about travel documents and travel related

documents from almost all countries in the world. The database is developed by the Dutch authorities in close co-operation with the authorities in Canada, Australia, USA, UAE and Interpol. Documentchecker is another reference database that allows organizations to inspect and authenticate international ID cards, driving licenses and passports and is only available for registered users. PRADO (Public Register of Authentic Identity and Travel Documents Online) is a website established by the Council of the European Union. It contains detailed information about European travel and ID documents and some of the security elements in these. iFADO is short for intranet Fraud and Authentic Documents Online. The website is operated by the Council of the European Union. The information is published by EU's member states. iFADO holds the most important information about security details in genuine ID and travel documents, visa and stamp impressions in the EU and some third countries.
Questioned Identification Document Database (QID) by the US Secret Service, Forensic Services Division permits real time comparison of suspect documents with images of genuine and other known counterfeit documents. The US Secret Service Printer Sample Database (US Secret Service, Forensic Services Division) has been used to identify the brand of printer used from the analysis of physical and chemical characteristics from a questioned document.
For forensic handwriting examination, again, several options are available. For example, the Forensic Information System for Handwriting (FISH) which is a database maintained by the U.S. Secret Service, enables document examiners to scan and digitize text writings such as threatening notes. By a series of plotted arithmetic and geometric values searches are made on images in the database, producing a list of probable matches. The International Ink Library & Digital Ink Library, maintained jointly by the U.S. Secret Service and the Internal Revenue Service, enters samples that are chemically analyzed and compared with a collection of library specimens. This may identify the type and brand of writing instrument, which can be used to determine the earliest possible date that a document could have been produced. CedarFox is used to compare a questioned document with a given set of known documents. It can associate a measure of confidence whether two documents are written by the same individual or by different individuals.
For more detailed information about other databases used by other forensic agencies, there is a comprehensive list available at http://www.nist.gov/oles/forensics/forensic-database.cfm.

Q2-3: If studies have not been conducted, what conclusions can and cannot be stated about the relationship between the crime scene evidence and a known suspect or tool (e.g., firearm)?
At this point, I believe is necessary to first categorize the diverse field of FSD based on substantial differences that exist among them. This fundamental distinction will help us understand the reason they cannot be treated in exactly the same way or with identical scientific approaches. Their intrinsic particularities have to be understood prior to searching the solution to the problems raised in the recent years of *contemporary forensics*. Then, we could classify forensic disciplines (i.e. types of evidence) in two different ways:

1. By their potential to identify the donor of origin:
   i. **Directly**: latent prints, ear prints, DNA, bite marks, handwriting, etc., that originate from a potentially unique biological (human) source and allows the individualization and identification of the donor.
   ii. **Indirectly**: shoeprints, firearms/toolmarks, questioned documents, etc. that give information about the surroundings of a crime and the tool/item used. They can relate potential suspects with a crime and link a crime with other crimes. However, they cannot provide the identity of a person.
   In the former case, population studies will be essential to find frequencies and trends that can reveal how common, relevant or unique specific types of, for example, latent prints or handwriting characters are. From these statistical studies, the strength of the evidence can be assessed and conclusions drawn based on degrees of probability. The latter, however, are circumstantial

evidence. They are evidence that complement the substantial (former) evidence and it helps build a case by placing more than one at a crime that appoint at the same subject. Population studies on the frequency of that evidence will be little informative and many times irrelevant although other statistical tests could be performed, for example, what is the most popular brand of sneaker in the city of Los Angeles among a specific segment of the population. Nonetheless, this study will never lead the investigators to the direct identification or individualization of a donor.

2. By their complexity to be modified (disguised) *ad libitum* before, during or after a crime by the donor:

i. **Easily**: handwriting, questioned documents, shoeprints, etc. which with little effort can be masked or manipulated.

ii. **Difficultly**: latent prints, ear prints, DNA, bite marks, etc. which would require a high degree of expertise to modify.

The former are evidence that can be transformed with little effort by any person at any time. For example, a person can disguise his/her own signature. In this case, the weight of this evidence and statistical tests have to be carefully applied and interpreted because there is a "natural" factor of disguise that can never be controlled. The latter are evidence that, unless time consuming surgery is performed (if possible), cannot be easily manipulated. In these cases forensic evidence is the strongest. Indistinctively of the class type, the factor *time* (or the "when" the evidence is left behind) will become essential for convicting a suspect as part of strengthening evidence. It is no longer a matter of finding evidence (the "what") and placing someone (the "who") at a crime scene but to prove that the suspect was at the crime when it occurred. For law enforcement, it would offer a new step in the current standardized protocols for crime scene analysis. In addition to *what* and *how* aspects of evidence collection, the ability to add the "*when"*could become a new phase in standard investigations worldwide.

Angi Christensen, Forensic Anthropologist, FBI Laboratory

My own doctoral research focused on developing a likelihood ratio method for comparison of frontal sinus morphology using Elliptic Fourier Analysis. Other have more recently published similar work or attempted to develop more user-friendly or automated methods for objectively assessing frontal sinus morphology and variation. The reliability of frontal sinus radiograph comparison (at least base on visual methods) appears well-established, but additional studies are needed to develop frequency-based methods. A colleague and I are actually currently working on developing a repository of documented skeletal trait frequencies that practitioners could reference in order to add baseline frequency data to their comparisons.

David Brundage, Ballistics Laboratory Director, Aegis Sciences Corporation

There are some published studies by various instrument companies that attempt to establish baseline frequencies of characteristics. Most of these studies are promising (see J. of AFTE @ www.afte.org); however, because the features examined by firearms and toolmark practitioners are microscopic and three dimensional they are difficult to attach a specific values.

Other studies are in progress, but have not been completed at this time. There are currently no specific databases for these types of studies due to the individuality of the characteristics on each specimen: bullet, cartridge case, or firearm. The conclusions that have been drawn from completed studies support those findings made by trained and competent practicing forensic firearm and toolmark examiners.

Any limitations for conclusions on the relationship between crime scene evidence and a known suspect (tool or firearm) has made by the court system. While such studies show that the work done by forensic examiners continues to be valid and accurate, some courts do not agree to the extent that is shown by research that has been completed.

Dr Rachel Bolton-King, Award Leader for Certificates of Professional Competence & Lecturer in Forensic Investigation, Staffordshire University

As mentioned in response to Question 1 above, the review paper ('Preventing Miscarriages of Justice: A Review of Forensic Firearms Identification') attached to this survey responds to some of these questions, especially the latter questions regarding conclusions the can and cannot be made about relationships between firearm and crime scene evidence.

With a focus on forensic firearm identification there has been research undertaken internationally regarding the frequency of class characteristics (such as general rifling characteristics; GRC) when applying the Bayesian approach to casework reporting. References to this are made in the review paper previously mentioned. Collaborative research is also currently being initiated by numerous European forensic science providers (e.g. Key Forensic) and academic researchers (such as myself) operating in the firearms arena with funding from ENFSI (European Network of Forensic Science Institutes) to further establish rifling (class characteristic) frequency data for submitted and inferred crime guns. Outcomes from this ENFSI funded research aim to result in the formation of a frequency database for use in casework.

Closed databases exist across the world (e.g. GRC, IBIS, IBIN, EvoFinder etc.) containing the 2D and/or 3D information regarding class and individual characteristics for fired ammunition samples (fired bullets, cartridge cases and shotgun wadding). The imaging hardware and associated database software is utilised to link crime guns to firearms evidence and/or linking firearms evidence across multiple crimes to establish a crime series potentially on an international scale due to transnational organised crime. The databases to undertake comparative firearm identification are typically controlled and curated by the manufacturing company e.g. Forensic Technology and there is no integration between these proprietary databases (eg IBIS and EvoFinder) to share and compare data/samples held within, which is a major limitation for proactive crime solving. In addition not all laboratories have funds to purchase such vital 3D technology to combat gun crime, having a major impact on the efficiency of the laboratory and capability of staff to process casework.

NIST have acquired funding from NIJ over last few years to generate an open access database of fired samples for research purposes where data can be submitted in a generic file format imaged using a range of hardware. I have made contact with NIST to supply such samples to expand their database, but there needs to be some training in how the database can be used by researchers and increased capability to add samples and expand the database for the resource to be utilised effectively especially from a research perspective.

Obtaining frequency data from individual characteristics from within fired evidence samples has been less investigated so there is some scope to explore this. Further comment is also provided in my review paper regarding the mechanism to look at frequency of individual characteristics, with some attempts to calculate probability being undertaken and referenced. However, due to the random nature that individual characteristics such as striations within toolmarks are created on tool surfaces and number of variables affecting toolmark transfer during the firing process (i.e. changes in width, relative location, frequency and depth) the calculation of frequency data from individual characteristics within these evidence types is not as confidently estimated in comparison to DNA profiling.

Joseph Prahlow - Professor of Pathology; Forensic Pathologist – Western Michigan University

Answering specifically for forensic pathology, again, while some or even much of what we do involves recognition of various patterns, it is wrong to classify FP as a "pattern-based matching technique" discipline, in the same way that fingerprint or DNA testing might be described. In those disciplines, "matches" can be made to the exclusion of all other individuals or explanations. In FP, as with virtually any other medical discipline, a diagnosis or an opinion is made to the best of one's ability, using all available information, etc... The diagnosis/opinion may not be to the total exclusion of all other possibilities. That is the reality of medicine. To attempt to "force" FP into a category/discipline to which it does not belong is not acceptable.

There is no earthly way to perform the experiments and create the databases that would be required to "validate" all, most, or even some of the diagnoses/opinions that are involved with the practice of FP.

Bridget Lewis - President, International Association for Identification

A list of ongoing research and development projects awarded by the NIJ can be found here:
http://www.nij.gov/topics/forensics/Pages/research-development-projects.aspx
The baseline frequencies of features in objects are from either unique or repeatable features on the objects. Natural features within patterns would occur once, repeatable features within patterns would occur as many times as those features are manufactured within those patterns.

It is important to note that the measurability of details in impressions or images is dependant upon the clarity or measurability of those details as recorded from the features of the source object. Details in impressions or images will have less quality and quantity of data, or information, that can be extracted from the features of the source object itself. This lesser measurability does not impart commonality or shared frequency if the details are from unique features on the source object.

Studies have been done (see provided source journals). But, it must be remembered that adding common terms to these details of unique features should not automatically impart commonality of frequency of occurrence. An example of this is adding the common term of 'ending ridge' to a feature in friction skin diminishes the appearance of uniqueness of that ending ridge in the source object or in the impression. Use of common terms for communication should not automatically imply shared shapes of features or details in natural patterns.

That features are inherently unique creates a problem with determining frequency. A threshold of commonality must be determined to categorize unique features by similar characteristics. Attempts have been made to study frequencies of occurrences of details and arrangements of those details, but data or information from those details is always lost when shared values of common terms are assigned to details of unique features.

Frequencies of repeatable features in manufactured items are difficult to study because of the aspect of how many times these features are produced through one manufacturer or many manufacturers. Plus, a variety of parts or sub-features can be grouped together to form different objects. An example of this is when the brand name in the mold for a shoe sole is changed, but the remaining features of the sole remain the same. Beyond production of objects with these features, it would be difficult to determine how many of these objects are actively in use within an area of interest.

Not too many open-access research databases exist. For some, see the NIJ and NIST sites:
1. http://www.nij.gov/topics/technology/pages/software-tools.aspx
2. http://www.nist.gov/forensics/ballisticsdb/
3. http://www.nij.gov/journals/258/pages/forensic-databases.aspx

Closed databases might exist from manufacturers of commercially produced products for training or testing providers. They are probably willing to sell to whomever is interested in buying the products. However, I am unaware how to produce multiple objects with the same frequency of the same unique features on multiple objects.

Conclusions in forensic comparative science examinations are based on the existing knowledge and available research within specific and related disciplines. The conclusions reached in comparative examinations

between crime scene impressions/images/objects and known people/objects/images are:

1. the information extracted from the details in the impressions/images/objects indicate they are not from the same source.
2. the information extracted from the details in the impressions/images/objects indicate they are from the same source.
3. the information extracted from the details in the impressions/images/objects is not sufficient to determine whether they are from different sources or the same source. Ranges of inconclusive decisions are often available within specific disciplines.
4. Various statements of conclusions are posted within documents of the various Scientific Working Groups. See these lists or links:

a. http://nij.gov/topics/forensics/lab-operations/Pages/scientific-working-groups.aspx
b. http://theiai.org/guidelines/index.php
c. http://www.nist.gov/oles/forensics/scientific_working_groups.cfm
d. http://www.nist.gov/forensics/workgroups.cfm

Many of the Scientific Working Groups (SWGs) have ceased future activity. As a replacement of the SWGs, the NIST Organization of Scientific Area Committees (OSAC) has been recently organized to coordinate development of standards and guidelines for the forensic science community to improve quality and consistency of work in the forensic science community. Conclusions and ranges within conclusions will be a part of this work. See: http://www.nist.gov/forensics/osac/index.cfm

Paul L Morrow - Forensic pathologist, Auckland, NZ, formerly Chief Medical Examiner, Vermont

Forensic pathology is not a pattern–based matching technique, but rather the medical diagnostic process based on the integration of "patient"(Case) history, physical examination and autopsy, and appropriate laboratory tests. The appropriate database for this is case dependent and it is in the greatest sense, the medical literature

Eoghan Casey, Multiple titles and affiliations related to digital forensics and cyber investigation

With the exception of cryptographic hashes such as MD5, limited formal studies are available for digital evidence to establish baseline frequencies of characteristics. Current efforts to create pattern databases of digital traces are not focused on statistical analysis, but rather on helping forensic analysts find and interpret digital traces. Certainly, there are some areas where frequency of characteristics could be important in relation to attributing activities to an individual. Consider Windows Security Identifier (https://en.wikipedia.org/wiki/Security_Identifier) which is designed to be unique on a Windows computer. When a Security Identifier of interest is observed in the Recycle Bin of removable media, is there is a 1 in 10 chance of collision, or a 1 in 1,000,000 chance of collision? As another example, patterns in computer usage referred to as behavioral biometrics, are being used to identify an individual, but further research is needed to assess the reliability of such patterns.

These questions apply to digital forensics, but are infeasible to answer in a general manner. Answers to the above questions depend on the specific kind of digital trace/pattern being considered, and their context. There are many characteristics in digital traces/patterns, including some that distinguish devices, e.g., manufacturer equipment identifiers, and others that differentiate individuals. There are many databases that contain characteristics related to digital evidence, including in-house databases, proprietary manufacturer databases, national databases, and international databases, some of which are only accessible or “need-to-know” under specific circumstances.

It is important to note that a study to establish baseline frequencies of characteristics is not the only way to determine the reliability or validity of digital traces/patterns. As one example, cell site analysis has been used to determine the location of a mobile device during a given time period. Although, results of cell site analysis have been validated, e.g., by revealing the location of a victim's body, critical evaluation and testing of some cell site analysis methods has revealed weaknesses, and motivated the development of more reliable techniques. In short, even when a forensic method is effective, there is always room for improvement, and it can never be 100% reliable.

Deion P. Christophe, Firearm Examiner III/Section Supervisor IFL/NMS Labs

Based on the most recent Optical Topography report published by NIJ, "NIST and the Federal Bureau of Investigations (FBI) have begun to collect reference data from test fires relevant to a wide range of firearms, including various combinations of research data, crime laboratory data, and instrument types. They have developed an XML data standard under the OpenFMC framework that could be used for interoperable sharing of ballistic identification data on a national basis. Many issues remain, including commercial acceptance, practitioner acceptance, the ability of laboratories to handle the large data files and computational load associated with topographic systems, and the collection of sufficient data to inform the development of analytical models." There are several closed databases that exist, ATF's NIBIN network being one of the most inclusive of all. This database is solely maintained by the ATF and monitored as well. The paradigm has however changed from searching for a gun based on the exhibits submitted on the back end to instead searching on the front end. The application of providing new investigative leads a new role supported fully by the AFT's NIBIN Network and newly created NIBIN Hit Center which will reside in Huntsville, Alabama. This approach will be very productive over time as it will support agencies that have not had the ability to establish baseline data such as the relationships between evidence and known suspect or tools, in this case firearms.

Professor Sue Black and Professor Niamh NicDaeid, Professors at CAHID, University of Dundee, UK

There are very few open access databases available relating to forensic evidence across almost any evidence type. Closed databases are limited by evidence type but would include fingerprint data bases such as those used in national and international AFIS systems and in the UK IDENT 1 system. There are also large databases relating to ballistic evidence which contain photographic representations of striated marks on bullets and other toolmarks on cartridge cases associated with individual weapons and generated through case work and test fired samples. These are linked to imaging systems such as IBIS and made available to firearm examiners. The necessity of closed databases is obvious as these would include live casework data. However, we would argue that such databases are not the most appropriate for the generation of pattern matching algorithms nor are then essential for the development of evaluative concepts (such as likelihood ratio analysis). Rather, closed casework databases are the test data to which the mathematical techniques need to be applied.

In order to develop scientifically robust and reliable pattern matching techniques, ground truth databases need to be generated. These databases should be reflective of the nature and variation of the material/evidence type under test but also of the variety of circumstances (surfaces, enhancement techniques, incompleteness of pattern etc.) that are encountered in the field. Academic institutions conduct database studies on a regular basis, however in our experience, much of this data is unusable as there are no agreed harmonised methods for conducting such studies and in many cases the data generated, with well meant intentions, is done so in a manner that is uninformed in terms of the operational context in which it would need to be implemented which renders it incomparable and essentially unusable.

Ground truth data bases, which match the sample generation to operational context are rare but some have been generated and at the University of Dundee these include a large fingerprint database, databases of surface images of landscaped features across the striation marks on repetitively fired pellets from the same weapon, databases associated with the clandestine production of methamphetamine, ecstasy and home made explosives and databases of ignitable liquids and databases of anatomical features (veins and other morphological features) of the hand and genitalia.

Ground truth database studies must be well planned with the overarching objectives well-articulated beforehand, and the appropriate database size across the desired variables understood from a mathematical perspective prior to the commencement of data collection. An interdisciplinary approach is essential so that academic researchers understand the operational context. Furthermore there is no reason for ground truth databases to be closed and open access, cloud sourced data is highly desirable. Once a robust protocol for data collection can be devised, there is no reason why cloud sourcing from across the global public community cannot be achieved. The value of the derived mathematical algorithms originating from such data to recognise patterns of known information would be comprehensive as the database size increases.

Without an understanding of the true nature of repeatability and reproducibility both of morphology and of measurement for a given evidence type and being able to place this information into a case context the strength of conclusions expressed will always be scientifically questionable. This renders them open to individual interpretation which of course has the potential to introduce a significant influence from human factors such as bias.

Michele Triplett, Forensic Operations Manager-King County Regional AFIS

Frequency Distributions of Data Although the frequency of characteristics is a factor for conclusions, the possibility of duplication has NOT been the reason for past errors in the pattern evidence disciplines. Errors have been the result of misinterpretation of data. Rules need to be stated to protect against misinterpretation of data BEFORE frequency distributions matter (i.e., frequency of actual features are useful but if the features are misinterpreted then the frequency distribution is not accurate). Other proposed models, such as the model for latent prints recently implemented at the Army Crime Lab, do not account for or protect against misinterpretation. Other models measure the frequency of features with the assumption that the interpretation is correct, which is an extremely false assumption. Correct interpretation cannot be assumed; as previously stated, misinterpretation was the reason for all known errors.

Assessing the Strength of a Conclusion on a Verbal Continuum Additionally, since the ambiguity and quantity of the data used determines the strength of the conclusion, this needs to be measured and reported out in order for others to know if a conclusion is weak or strong. Many have attempted to quantify conclusions numerically by measuring frequency distributions (either with a point standard or a probability model) but current methods are lacking since they do not account for misinterpretation of features. A verbal scale that accounts for the ambiguity of features can and should be implemented until a mathematical scale can be achieved. Verbal scales are common in disciplines that cannot be mathematically quantified, such as the American Hospital Association guidelines when describing a patient's condition (stable, serious, critical, etc.). Again, see attached paper.

Xhemajl Ademaj, Fellow American Academy of Forensic Science

Regarding the achievements such as reliable is IBIS data base which gives accurate blow to the evidence from the crime scene with records in the system, for casings and shells.

Michael T. Beddow, Forensic Scientist IV, Phoenix Police Department Crime Laboratory

Within the field of Forensic Firearm and Toolmark Examination the primary features utilized during the comparison process are microscopic toolmarks of either an impressed or dynamic nature, and/or both in many circumstances. Each toolmark will be evaluated for the class characteristics, potential sub-class characteristics and ultimately their individual characteristics. The Association of Firearm and Toolmark Examiners (AFTE) has developed a "Theory of Identification as it Related to Toolmarks" that is followed by competent firearm examiners both in casework and research. This same process is also followed during the training of a new firearms examiner. Below is a copy of the "Theory of Identification as it Related to Toolmarks" as published by AFTE.

Theory of Identification as it Relates to Toolmarks

1. The theory of identification as it pertains to the comparison of toolmarks enables opinions of common origin to be made when the unique surface contours of two toolmarks are in "sufficient agreement."
2. This "sufficient agreement" is related to the significant duplication of random toolmarks as evidenced by the correspondence of a pattern or combination of patterns of surface contours. Significance is determined by the comparative examination of two or more sets of surface contour patterns comprised of individual peaks, ridges and furrows. Specifically, the relative height or depth, width, curvature and spatial relationship of the individual peaks, ridges and furrows within one set of surface contours are defined and compared to the corresponding features in the second set of surface contours. Agreement is significant when the agreement in individual characteristics exceeds the best agreement demonstrated between toolmarks known to have been produced by different tools and is consistent with agreement demonstrated by toolmarks known to have been produced by the same tool. The statement that "sufficient agreement" exists between two toolmarks means that the agreement of individual characteristics is of a quantity and quality that the likelihood another tool could have made the mark is so remote as to be considered a practical impossibility.
3. Currently the interpretation of individualization/identification is subjective in nature, founded on scientific principles and based on the examiner's training and experience.

The above Theory of Identification is what allows for the establishment of our "baseline frequency" with regards to our comparative analyses. The best description of our evaluation of the "baseline frequency" is listed theory above as it states "*Agreement is significant when the agreement in individual characteristics exceeds the best agreement demonstrated between toolmarks known to have been produced by different tools and is consistent with agreement demonstrated by toolmarks known to have been produced by the same tool".* Utilizing this theory allows for competent examiners to evaluate toolmarks and only author an opinion of a positive association when the level of pattern correspondence exceeds that of the greatest pattern correspondence found in toolmarks produced by two different tools: this being known as the best known non-match.

This theory has been studied on many different levels: specific research projects, training assignments for new firearms examiners requiring extensive observation and analysis of known non-matches, and the observation of virtually an unlimited number of known non-matches via routine casework. The most beneficial research projects that have been conducted have been those related to the evaluation of specific machining methods and their resulting toolmarks as well as the many studies investing the idea of consecutively manufactured tools. The consecutively manufactured tool studies not only allow for the evaluation of the machining methods but also allow for the evaluation of the potential for carry over or sub-class characteristics. Multiple studies of these types were referenced in the response to question number one of this questionnaire, however, they are not limited to these few studies, as many more have been completed and published throughout the history of this field of forensic science. Research projects have

also been conducted with relation to statistically evaluating the possibility and probability of random correspondence between two toolmarks that are a known non-match. These projects have been both objective and theoretical.

To date all of the objective and scientific observations/research and theoretical calculations have supported the methods and conclusions that have been reached by Forensic Firearms Examiners over the many years.

At the current date there are no existing databases, public or closed, that contain data that could be utilized to establish or has helped to establish our "baseline frequencies". There is one primary reason for this: each toolmark is into itself unique or contains within it unique features. Therefore, by the pure definition of uniqueness, a generic "baseline frequency" cannot be established that will or could be applied in general to all toolmarks. When statistical mathematics has been applied to measured and theoretical toolmark comparisons, the conclusions reached have been generally the same as that reached via traditional optical toolmark comparisons followed by an expert opinion. Unlike DNA, that has a fixed number of possible points of comparison, the reason that a basic mathematic equation has not been generated, nor do I believe can be generated, to provide a statistical answer to the level of correspondence between toolmarks is that there is a virtual infinite number of possible sizes, shapes, locations and orientations of individual characteristics within a whole toolmark.

In firearms and toolmark identification, performance testing (as defined above) is determined by a series of different tests and experiments. First, the overall reliability of a trained examiner to correctly differentiate and associate items based on the comparison of microscopic toolmarks has been demonstrated through nearly a century of empirical research, validation tests, and proficiency test data. Furthermore, over the past decade, research using 3D topographical data and comparison algorithms provides strong, statistical support for the firearm and toolmark examiners experiential knowledge.

Within the laboratory, firearm and toolmark examiner training is often the most rigorous and time-intensive of all the forensic disciplines. A typical trainee will train for at least two years prior to performing any casework. Once the trainee has completed their training, they will be presented a series of competency tests. Following successful completion of these tests, they will advance onto performing monitored/supervised casework, after which they advance to journeyman level status and are qualified to perform full casework. Typically, post training, examiners are required to complete (at least) one proficiency test a year in each discipline they are qualified. Data has been collected from published results from commercial proficiency tests providers. This data has been used to evaluate potential error rates within the field. However, this data must be used with caution as the commercial providers do not control for the level of training or prior competency before issuing a test and recording the results. The evaluation of an individual examiner's performance on proficiency tests is often monitored by a laboratory quality assurance manager (Question #3 References, [1]).

The proficiency test is generally not blind; however, the correct answer is not known by the examiner. In order to combat some of the challenges in providing a truly blind test, some laboratory systems do periodically test examiners blindly through a re-examination process or a blind verification process. However, these practices anticipate a consensus opinion, and the answer is not one grounded in truth like the current proficiency test method. It would be extremely difficult to produce a truly blind test in a forensic laboratory. These considerations and complications of implementing blind forensic proficiency tests are well outlined in the articles by Peterson, et al (Question #3 References, [2,3]). To highlight some of the difficulties: The test provider(s) would have to produce fake reports, evidence, packaging, and all other documentation in order to make the evidence appear "real". Additionally, with many laboratory systems

carrying case work backlogs, in order to not bias the examiner and treat the test blindly, it would have to be subject to the same timeliness criteria as other cases. This task alone is herculean given the patchwork nature of United States Forensic Laboratories. Furthermore, law enforcement investigators would have to submit requests to examine this evidence, and then the laboratory would have to ensure each examiner is provided a test, but do so in a "blind" manner. It is our opinion that this is not a practical use of laboratory resources (both cost and manpower). We are only aware of the studies referenced above (Peterson et al).

Clifford Spiegelman, Distinguished Professor Texas A&M U

See Law, Probability and Risk (2012) 0, 1–19 doi:10.1093/lpr/mgs028
Analysis of experiments in forensic firearms/toolmarks practice offered as support for low rates of practice error and claims of inferential certainty

Brandon Giroux, President, Association of Firearm and Tool Mark Examiners (AFTE)

There are two main types of toolmarks considered by the firearm and toolmark examiner; impressed and striated.

- Impressed toolmarks are, as the name implies, created when a harder tool working surface strikes, or comes into contact with, a softer surface with sufficient force to create an impression.
- Striated toolmarks are created by a sliding motion where a harder tool working surface, like the rifled bore of a firearm, or the edge of a screwdriver, makes contact with a softer material, like a fired bullet or edge of a metal door frame. Parallel lines, called striae, of varying width, are formed.

Pattern-Matching is the criteria for identification method of toolmark comparison and identification that is utilized by forensic laboratories throughout the US. The Association of Firearm and Toolmark Examiners (AFTE) Theory of Identification (adopted by AFTE in 1993 and slightly revised in May 2011) states the following:

AFTE Theory of Identification as it Relates to Toolmarks

1. The theory of identification as it pertains to the comparison of toolmarks enables opinions of common origin to be made when the unique surface contours of two toolmarks are in "sufficient agreement."
2. 2. This "sufficient agreement" is related to the significant duplication of random toolmarks as evidenced by the correspondence of a pattern or combination of patterns of surface contours. Significance is determined by the comparative examination of two or more sets of surface contour patterns comprised of individual peaks, ridges and furrows. Specifically, the relative height or depth, width, curvature and spatial relationship of the individual peaks, ridges and furrows within one set of surface contours are defined and compared to the corresponding features in the second set of surface contours. Agreement is significant when the agreement in individual characteristics exceeds the best agreement demonstrated between toolmarks known to have been produced by different tools and is consistent with agreement demonstrated by toolmarks known to have been produced by the same tool. The statement that "sufficient agreement" exists between two toolmarks means that the agreement of individual characteristics is of a quantity and quality that the likelihood another tool could have made the mark is so remote as to be considered a practical impossibility.
3. Currently the interpretation of individualization/identification is subjective in nature, founded on scientific principles and based on the examiner's training and experience.

Attempts have been made in establishing a more objective criteria called Quantitative Consecutive Matching Striae (QCMS) which is in use by some firearm and toolmark examiners; however, it is not yet employed universally. QCMS is a way of describing in numerical terms an identification after traditional pattern matching methods have been employed. Once a pattern is found, the striations are tabulated and compared

against the QCMS baseline. It should be noted that currently QCMS can only be employed when striated marks are involved and is not yet capable of capturing impressed marks which are routinely encountered by examiners in casework.

Creating baseline frequency studies is a difficult proposition in the field of Firearms and Toolmarks Examination due to the dynamic nature this type of evidence presents. Given there can be no degree of control over the absence or presence of affected surface areas that may contain baseline marks makes the use of a standard frequency database difficult. However, in recent years research has been and continues to be conducted using computer technology to begin formulating criteria and to assist in creating objective, measurable standards for identification within the field.

Q2 Part 2: What publicly accessible databases exist that could support such studies? What closed databases exist? Where such databases exist, how are they controlled and curated?
Databases designed to establish the baseline frequencies of characteristics or features used to establish identity for forensic firearm and toolmark comparisons currently do not exist.

Q2 Part 3: If studies have not been conducted, what conclusions can and cannot be stated about the relationship between the crime scene evidence and a known suspect or tool (e.g., firearm)?
The conclusions that can be rendered between two toolmarks are Identification, Elimination, Inconclusive and Unsuitable, and are defined below:

AFTE Range of Conclusions
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:

B. Agreement of all discernible class characteristics and some agreement of individual characteristics, but insufficient for an identification.
C. Agreement of all discernible class characteristics without agreement or disagreement of individual characteristics due to an absence, insufficiency, or lack of reproducibility.
D. Agreement of all discernable class characteristics and disagreement of individual characteristics, but insufficient for an elimination.

Elimination:
Significant disagreement of discernible class characteristics and/or individual characteristics.

Unsuitable:
Unsuitable for examination.
Many forensic laboratories require competency testing prior to authorization for a forensic practitioner to independently evaluate evidence.

Proficiency testing is a valuable component to measure the performance of individual examiners and the procedures, methods and practices utilized by the laboratory. Forensic laboratory accreditation bodies generally require each laboratory participate annually in proficiency tests provided by an external vendor, if available. Currently, the requirements do not mandate that each examiner participates in an external proficiency test, though most forensic laboratories exceed this standard and require that each examiner participates in an externally provided proficiency test. There are currently two (2) vendors that provide

external proficiency tests in the area of Firearms and Toolmark Identification. One of the vendors does not provide, report or publish a statistical evaluation of the compiled results submitted at this time; however, laboratories can review the test summary provided for a particular test to extrapolate this information. The other vendor is offering a proficiency testing scheme with calculations of statistics relevant to the forensic science and legal communities to include false positive and false negative error rates, as well as sensitivity and specificity for each test.

American Academy of Forensic Sciences (AAFS) Board of Directors

This may be addressed by the responses provided above for Q1. If a study involves a database, it is often cited in the study. Additional studies in the area of questioned document examination include the following: references provided.

Additionally, there are many databases in existence. A database may be limited in scope in that it may be either an in-house database or a proprietary manufacturer database. Databases also exist at the national and international levels. It could be a publicly accessible database, such as SICAR® 6 and SoleMate® maintained by Foster+Freeman. When used in conjunction, the two databases aid in the identification of shoe prints recovered from crime scenes and the management of shoe print evidence. Other examples include the Integrated Ballistic Identification System (IBIS) maintained by the Bureau of Alcohol, Tobacco, Firearms and Explosives for bullets and cartridge casings; PDQ maintained by the Royal Canadian Mounted Police for the chemical composition of paint from most domestic and foreign car manufacturers and the majority of vehicles marketed in North America after 1973; and the Integrated Automated Fingerprint Identification System (IAFIS), the Combined DNA Index System (CODIS) and the National DNA Index System (NDIS), all maintained by the Federal Bureau of Investigation.
Closed databases also exist, such as the "Frequency Occurrence of Handwriting and Hand-Printing Characteristics" database. This particular database exists in the form of two Microsoft Access Spreadsheets, one for cursive writing and the other for printed writing, in the possession of Tom Vastrick, Ellen Schuetzner, Heather Burske, Mark Johnson and Michele Boulanger.

Jill Spriggs, President, CA Association of Crime Lab Directors

Studies have been conducted to different extents regarding the frequency of characteristics in the various pattern-based forensic disciplines, so again the OSAC subcommittees should be tasked with developing a comprehensive list of these studies. They can also put forward a suggested plan for future research to provide frequency information where needed.

It is important to recognize that many of the solutions used in forensic science are already using probability-based criteria for candidate hits. For example, mass spectral libraries, Automated Fingerprint Identification Systems, and cartridge case and 3D bullet correlation databases are all dependent on imaging and matching algorithms based on probabilities. Many of these are in the public domain (e.g. mass spectroscopy), but most are owned by vendors and solution providers. Additionally, there are many current academic research projects studying probability models, especially fingerprints. Universities in California and in other states have received grants to study these probability models.

Studies can take two approaches: the digitization of images and algorithms used in pattern databases, and also studies to determine the efficacy of training examiner comparisons. The latter depends on submitting case samples to a pool of tenured examiners for comparison. (The process is very similar to current proficiency testing, but with a greater quantity of cases.) The former requires electronic examination of patterns, developing probability models to quantify similarities, and then comparing the electronic models

to the expert opinions of forensic professionals.

The majority of forensic service providers use these databases for candidate hits, not conclusions. Comparison conclusions are made by trained examiner analysis.

Finally, these databases must be government controlled (though transparent in administration) and non-proprietary. Very similar to national AFIS standards managed by the FBI, all pattern databases should have published foundation and development, but be available to all laboratories and vendor solutions. The formatting of the database should be vendor independent with full specifications for submitting, searching, and retrieving. By ensuring an open, non-proprietary system, the greatest availability and cooperation is achieved.

Randy A. Sandifer, Forensic Scientist, American Academy of Forensic Sciences

Yes, there is CTS testing which is considered proficiency testing which allows for all practicing examiners to participate in a blind testing within their individual discipline. Each participant is given a code which is assigned to that individual examiner. When the results are released there is list of results given each examiners' personal code listed in a database. This data base creates a baseline view of how each examiner skills are matched with other examiners given the same unknown specimen. The database for CTS testing can be found on the website CTS.

In relation to evidence, that is used for forensic purposes. The evidence is limited in stating that someone actually pulled the trigger. Because the firearm belongs to someone or the firearm has been used in a crime doesn't actually mean that the owner actually pulled the trigger. Often times firearms are stolen and used to commit a crime. In such case the owner may or may not have file a report concerning the firearm being missing. Thus, this is the limitation of forensic evidence.

Consortium of Forensic Science Organizations

While the forensic science community in the U.S. is getting better at publishing data, every lab in the country had a treasure trove of validation data that is not usually published in scientific journals. Labs have been historically been protective of this data being released in a general way. Many labs are looking for ways to have their internal validation data evaluated by other scientists and statisticians. PCAST could evaluate effective partnerships that might lead to more labs being willing to publish this data in scientific journals or at the very least on their agency websites.

Perhaps close to 100 or more forensic science conferences are held each year. Forensic science conferences and symposia have become better at publishing a “proceedings” document after the conference, but many historical and current presentations are not published anywhere. To emphasize this point, the upcoming annual meeting for the American Academy of Forensic Sciences (AAFS) had 56 submissions and will have 41 scientific presentations on research related to the disciplines mentioned by the recent PCAST survey. While the academy does publish these in a “proceedings,” and many of them are published in the AAFS Journal of Forensic Sciences, many smaller conferences do not have the resources of AAFS to be able to publish the research presented. PCAST could possibly recommend some mechanisms or incentives for more scientific presentations to be converted into peer reviewed publications.

Matt Johnson, Orange County Sheriff’s Department

Currently, a limited number of databases exist which can be used for classification of footwear outsole patterns. However, no study has been conducted on the frequency of outsole pattern designs or manufacturing characteristics. This is due in large part to the number of factors that must be accounted

for in order to complete such a study. For example, shoe manufacturers do not provide details on how many shoes of a specific design are made or where they are sold. In addition, there are a number of counterfeit shoes on the market which copy the outsole design of popular shoes. Furthermore, once shoes are bought, it is unknown how long each person keeps a single pair of shoes, so it is near impossible to estimate how many shoes of a given make/model are in the population at a given time.

Existing Pattern Databases?

- Raven Technology/National Footwear Reference Collection – UK (30,000 patterns)
- Everspry – China (now USA – EVIDENT sells a database with 20,000 patterns)
- SoleMate – SICAR (Foster & Freeman – 33,000+ patterns)

Existing Private Databases?

- Girod, A., (1996) Computerized classification of the shoeprints of burglar's soles. Forensic Sci. Intl., 82(1) Forensic Technical Laboratory in Neuchâtel, Switzerland – 1500+ reference files.
- Belser, Ch., Ineichen, M., Pfefferli, P. (1996) Evaluation of the ISAS system after two years of practical experience in forensic police work Forensic Science International, Volume 82, Issue 1, 53-58 Zurich Cantonal Police - 10,000+ images.
- Mikkonen, S., Astikainen, T. (1994) Databased classification system for shoe sole patterns: Identification of partial footwear impression found at a scene of crime Journal of Forensic Sciences, Volume: 39 Issue:5, 1227-1236 Finland in-house database.

To date, there have been two major studies which have assessed the baseline frequencies, and potential co-occurrence, of RACs found in footwear impressions [1, 2], in addition to several smaller studies. The first large empirical study was conducted by Cassidy in 1995, and the results provide a baseline numerical estimate for the probability of repeated RACs based on a dataset of boots worn by police recruits. Given that all shoes were worn for the same time span and while traversing the same terrain, conditions favored the chance reproduction of features [1]. Two impressions from each of 97 shoes were recorded and the shoes were broken into two groups A (59 shoes) and B (38 shoes) based on the presence of a heel on the boot. From each impression, three accidentals were selected and compared against all other shoes for duplication in position, ignoring shape and complexity. Results indicated that for minute characteristics, the greatest potential for random co-occurrence was about 1 in 6. Furthermore, the results for moderately sized characteristics indicate that these features are less likely to be duplicated (probability ranged from 1:20 to 1:38) [1]. The author concluded that quality of features greatly affects the chance of encountering a duplicate accidental. More specifically, features which are small or of poor quality require a larger number of features to reach identification while large and more complex features are more individualizing.

Similarly, in an effort to characterize the chance for random duplication of accidentals, Stone (2006) utilized theoretical probabilities. More specifically, the hypothetical probability of encountering two RACs on different shoes with the same position, shape, and orientation was computed. To arrive at the computed probabilities, a hypothetical 16,000 square millimeter grid was superimposed on a theoretical shoeprint. For a point characteristic, the probability of random co-occurrence was modeled as 1 in 16,000. For a line, the length, orientation, and position were combined to obtain a potential for duplication of 1 in 384,000. Furthermore, when considering the position, length, orientation, direction of curvature, degree of curvature, and apex location, curves were computed to possess a 1 in 19,200,000 probability of finding a given curve characteristic on another shoe. Therefore, as characteristics become larger and more complex, the chance for random duplication greatly decreases [2].

Existing RAC Databases?

- Israeli Police Suspect Database – 400+ shoes with 13,000+ RACs (http://www.samsi.info/sites/default/files/Yekutieli_august2015.pdf)
- WVU HQ Database – 1,000 shoes, 57,000+ RACs

Currently, there are two major conclusions scales that are used for footwear comparison results. In the United States, the SWGTREAD conclusion scale is utilized by many forensic laboratories [3]:

1. Lacks sufficient detail
2. Exclusion
3. Limited associated of class characteristics
4. Association of class characteristics
5. High degree of association
6. Identification

Conversely, in Europe, the conclusion scale developed by the ENSFI Marks subcommittee is a common standard for footwear comparisons [3]:

1. Elimination
2. Likely not the source of the impression
3. Inconclusive
4. Probably the source of the impression
5. Very probably the source of the impression
6. Identification

Works Cited

(1) M. J. Cassidy, Footwear Identification, Lightning Powder Company, Inc., 1995.
(2) R. S. Stone, "Footwear examinations: Mathematical probabilities of theoretical individual characteristics," *Journal of Forensic Identification,* vol. 56, pp. 577-599, 2006.
(3) S. Hancock, R. Morgan-Smith and J. Buckleton, "The interpretation of shoeprint comparison class correspondances," *Science and Justice,* vol. 52, pp. 243-248, 2012.

Question 3 – Performance testing

How is performance testing (testing designed to determine the frequency with which individual examiners obtain correct answers) currently used in forensic laboratories? Are performance tests conducted in a blind manner? How could well-designed performance testing be used more systematically for the above pattern-based techniques to establish baseline error rates for individual examiners? What are the opportunities and challenges for developing and employing blind performance testing? What studies have been published in this area?

Itiel Dror, Senior Cognitive Neuroscience Researcher, University College of London

The problem is beyond 'when an individual examiner obtains the correct result', but that examiners:
1. Do not get the same results (both with one another, and even with themselves at Time 1 and Time 2).
2. That examiners (in addition to basic inconsistency) are influenced and biased by irrelevant contextual information that they are most often exposed to.
3. One needs to study the cognitive factors the influence forensic decision making --attached are three published papers on these issues.

Stephen E. Fienberg, Maurice Falk University Professor of Statistics and Social Science, Carnegie Mellon University

I have seen no effective performance testing from forensic labs that would allow us to assess the quality and accuracy of forensic laboratory and examiner error rates.

Steven Johnson, Board Chair - The International Association for Identification

Most laboratories require proficiency testing to ascertain competence levels of the examination staff. These are generally conducted annually and the source of these tests is external. While blind testing is encouraged, many organizations let their examination staff know they are being proficiency tested and this could (potentially) skew the results. Ideally, an accepted standard for proficiency testing that could applied across the spectrum of FSSPs would be most appropriate.

C. Michael Bowers, Board Chair - odontologist. Ventura Medical Examiner

These dental experts have made three attempts (1986, 1999, and 2015) to establish proof of reliability amongst its practitioners (N=39). None have been successful.

Joe Cecil, Senior Research Associate; Division of Research; Federal Judicial Center

Performance tests are often conducted on an announced basis using samples that do not approximate the complexity of samples that often are presented to such experts.

Frederick R. Bieber, Professor, Harvard Medical School

The technical review process in forensic labs is deficient and not blinded. Examiners are subject to confirmation bias at several steps in the process. While "blinded testing" is difficult to arrange for crime labs, it can be done and should be.

Mary Beth Hauptle, Professor, Forensic Odontologist, FCMEO

Members of the ABFO, forensic odontologists "qualified" in their opinion to analyze bite marks have recently shown no consensus. Proficiency of practitioners has a known error rate of 64 %.

Tatiana Maria Blanco Alvarez, MA, Graduate student TTU

As far as the literature reviewed to the moment, there are not many studies that address the issue of performance testing in a bling manner. The laboratories used these kinds of test depending on the time they have to do conduct them, the relevance they have and the procedures that have been stated for each lab. A way to used them more systematically could be by standardized a protocol, with enough evidence to support it, and established as the protocol that every forensic lab needs to follow. The opportunities to do it depends on the time each lab has to conduct them as well as how useful they are to the people conducting them; the challenges are the lack of standardized protocols, and the culture to conduct blind performance test.

Femblix Meek Tom Jr, Student Citizencorps.gov AAFS.ORG Fvtc.edu Dna.gov Wvu.edu Bronx Community College

Every First responder should know about DNA crime lab Forensic general collective analysis and interpretation related to the incident. Water base pattern cold case elderly or twins blood biometric finger analysis sometime back log Past five Bi-annually investigation data survey lock evidence court room communication unclassified due to insufficient material body fluid Str technology

Pierre Margot, Emeritus Professor, University Lausane

I cannot judge for forensic laboratories, but university research is using blind studies to test current methodologies (see publications question 1)

Mark Leney, Professor, UMass Medical School and Deputy Director, MassBiologics

In anthropology, performance testing is primitive. The issue of the curation of human remains continues to be an issue in obtaining and storing standard materials that could be used to operate and validate blind testing samples, either for competency or proficiency.

Eric Warren, Ph.D., Special Agent/Forensic Scientist, Tennessee Bureau of Investigation

In forensic laboratories, individual examiners are given annual blind proficiency tests (a test contracted to a third party company who does not reveal any information to the laboratory other than to examine the indicated items and make a determination on their origin – Identification, Inconclusive, or Elimination) in each discipline in which they are trained. After the results have been submitted to the third party company, the results are sent to the laboratory and maintained in the record of the individual examiner. I think performance tests (proficiency tests) are well-designed and currently being used in the best manner possible. The challenges are making the tests as true to real life cases as possible and keeping the costs down so that forensic laboratories can afford them on a limited budget. Some of the following articles have addressed this issue. See references.

Robert Gaensslen, Prof Emeritus, Univ of Illinois Chicago

To my knowledge it mostly is not. Most proficiency testing (PT) is open, not blind. Some labs and systems do blind testing but it's internal. And all it catches is the occasional incorrect answer - say the test is done every 6 mo or a year. We did a big project on blind DNA PT. It is not simple. You have to get a case into the lab disguised as evidence. Some people on our advisory board didn't like the idea that you have to get law enforcement to lie to the labs for the supposedly greater good of blind PT. These results are in J forensic Sci. Sometimes, the police tipped off the lab about the test. With DNA and perhaps with other complex criminalistics cases, it is hard to do enough PTs to get a good number. If you test a DNA examiner 2x per year, that's a lot. But it doesn't give you good numbers. It is much easier with drug chemistry or toxicology. One non-trivial issue in PT is defining what is to be considered correct. Say an examiner reports 'inconclusive'. Is that wrong? You have to decide in advance, have a reason (such as most labs can do it), and let the test subjects know what is going on. There are older PT studies summaries in J Forensic Sci from Joe Peterson.

Dr. Sushil Kumar Sharma, Editor, EC Chemistry, UK

The benefits of discipline-specific proficiency testing include: Demonstration of a laboratory's ability to satisfy, on an ongoing basis, accreditation or certification requirements and ongoing competency; Comparison of an individual's or a laboratory's performance with that of another; Identification of methodological problems, transcription error patterns, or other undetected performance weaknesses and initiation of actions for improvement; Establishment of the effectiveness and comparability of test or measurement methods and, through the provision of metrics that could be analyzed, interpreted, and published, facilitation of further standardization of laboratory procedures and best practices; Validation of uncertainty claims; Enhancement of stakeholder confidence in the reliability of forensic science providers' work products. In its most comprehensive form, forensic science proficiency testing involves three distinct entities: forensic science service providers, proficiency test providers, and bodies that accredit the test providers. Proficiency test providers use a variety of testing mechanisms, including open or declared (in which participants know they are being tested); blind (in which participants do not know they are being tested); and re-examination testing (in which an examiner's completed prior casework is randomly selected for reanalysis). It is recognized that there are areas of testing and calibration in which suitable PT is not available or practical. When such PT programs are not available or relevant to the scope of accreditation, A2LA will rely on the aforementioned "quality control" checks in accordance with clause 5.9.1 of ISO/IEC 17025:2005 for assuring the quality of testing and/or calibration results. Quality control checks may include (but are not limited to) the following types of activities: regular use of certified reference materials and/or internal quality control using secondary reference materials; replicate tests or calibrations using the same or different methods; re-testing or recalibration of retained items; and correlation of results for different characteristics of an item. The results of these quality control checks do not need to be provided to A2LA. A

representative sample of these internal checks will be reviewed on-site by the A2LA assessor during the full on-site assessments as a part of their usual assessment.

Moses S Schanfield, Professor, Department of Forensic Science, George Washington University

As a member of the DAB Blind Proficiency Panel, it is accepted that the "blind analyst" model is about as good as it is going to get. To try and blind everything, has the potential of unforseen consequences. As a previous preparer of the AABB Parentage Testing Proficiency Panels, I believe proficiency exams should be centrally prepared and distributed, such that a large number of analysts, whether fire arms, finger print etc take the proficiency test so that outcomes can be compared on a national bases. This will generate national, laboratory and individual analyst rates of errors. There is no way to have true blind proficiency testing without a supplying law enforcement agency lying on a submission, leading to possible trust issues, and further, none involved material being entered into federal and local databases.

Abigail Lehman, Criminalist III, Missouri State Highway Patrol

We are given PT tests annually and are evaluated internally as well as externally. These are not conducted in a blind manner which would be the ideal method for administering these tests.

Rigo Vargas, QD Section Chief, MS Forensic Laboratory

The most widespread performance testing is done via bi-annual proficiency tests administered by Collaborative Testing Services (CTS). Other performance tests come from volunteering to participate in skill assessment based research projects; The Australia and New Zealand Documents Specialist Advisory Group (Doc-SAG)is running a Skills Validation Project for the following Examination Types:

- The comparison of text-based signatures with handwritten text
- Altered and obliterated documents
- Printing process identification
- Stamp comparisons
- Ink comparisons
- Interpretation of ESDA
- Tear match comparisons
- Office machine identification and linking

Results of this study will be available mid-year 2016. Are performance tests conducted in a blind manner? No.

What are the opportunities and challenges for developing and employing blind performance testing? Blind testing in the forensic arena would be a logistical and financial nightmare. Attempting such testing would be a futile waste of time, energy, resources, and money.

Marianne Stam, Retired (in 2015) Criminalist Supervisor

There is competency testing of the individual in which they must prove competency before they can perform casework; there is continuing proficiency testing thereafter. Proficiency tests are generally not double blind due to the need to have an outside agency willing to submit a blind test to a laboratory by establishing a chain of custody for non-real evidence and then having an investigating officer ready to answer questions about the 'case' should the forensic scientist feel the need to contact the agency for further information etc... A 'single blind' test that is blind to the actual analyst has been done before and is usually an internal proficiency test - but again it runs into the issue of having to have an outside agency establish a non-real chain of custody and have someone available to answer 'case' questions in order to make it realistic.

Michael Kusluski, Forensic Scientist, Michigan State Police

Error rates for individual examiners (or even labs)is not a realistic goal. It would require much more testing than is practical. (Though many researchers mistakenly discuss individual/lab error rates, the Daubert rule describes discipline-wide rates only). A more practical goal in the short term would be to establish reliable discipline-wide error rates. The studies performed to date are very wanting. Giving every examiner a blind test every year is impractical. But as Saks/Koehler have suggested, making every examiner in the country to be eligible for a blind test would be manageable.

James DiFrancesco, Forensic Biologist/ U.S. Army Criminal Investigation laboratory

Proficiency testing is currently employed in our laboratory. The tests are a good way to test the individual examiners competence as well as the quality system of the laboratory.

Dr. L. Thomas Johnson, Professor (Retired) Marquete University

Inter and Intra observer consistency was conducted in a series of five studies on quantifying 8 dental characteristics of the human dentition based upon three research awards from the Midwest Forensic Resource Center, Ames Laboratory, Iowa State University.

Howard A. Harris, Professor Emeritus

All accredited labs have multiple performance testing as well as the court system (role of defense is to test prosecutions results!

Dr. Geoffrey Stewart Morrison, Independent Forensic Consultant; Adjunct Associate Professor, Department of Linguistics, University of Alberta

A human operator who performs part of the analysis is part of the system, and the whole system must be tested including that particular operator. As explained in my response to Question 1, testing should be performed on a case by case basis. At present there is a great dearth of such testing on forensic voice comparison practice. See the papers on testing referenced in my response to Question 1, particularly: Morrison (2011), Morrison (2014), Enzinger et al (2015), Enzinger & Morrison (2015).

Glen Jackson, West Virginia University

In the area of drug analyses, several independent bodies (like CTS and FIRMS) offer blind proficiency tests in a variety of areas. These results can evaluate error rates for knowns, but there is no way to evaluate the error rate for unknowns.

Josep De Alcaraz-Fossoul, Researcher and Assistant Professor, University of Barcelona

Q3-1: How is performance testing (testing designed to determine the frequency with which individual examiners obtain correct answers) currently used in forensic laboratories? Are performance tests conducted in a blind manner? Most laboratories are implementing international standards for checking the performance of the organization and its experts. There are several ways of conducting these tests and evaluate the effectiveness of the examiners:

1. Accreditation/certification of the laboratories and experts respectively, based on daily casework or interlaboratory tests.
2. Use of international standards and best practice manuals from agencies of reference. Including FBI, AAFS, IAI, SWAG, ENFSI, Interpol, ASCLD, ISO, etc.
3. Proficiency testing of experts by other experts of the same or different organizations.
4. Continuous education and/or graduate (post-graduate) degrees from validated institutions.
5. Regular training and updating skills.

In the USA the term known as the ABC's process is used and the third step of this process is about competence and individual certification as a way of demonstrating a person's ability to provide results and interpretations of forensic analysis. How this ability is assessed can really only be through full independent Proficiency Testing. This must be used as a vital part of any organisational and individual accreditation/certification process. There are many advantages of adopting this approach not least the fact that the Proficiency Test co-ordinator knows the result that should be achieved and the expectations of the test. If the true outcome is known then competence to achieve the correct result by an individual can truly be assessed. By gathering trend data relating to the success or otherwise of individual participants to gain the correct result/interpretation will hen provide an error rate which can be factored into any analysis which should be declared as a limitation of any analysis the trend data relates to. This is the only effective way to assess competence.

European laboratories are determined to achieve ISO17025 accreditation for the various areas of forensic science in 2015. Those not accredited by November 2015 will not be able to practice according to European law. To satisfy the personnel part of the ISO17025 standard, laboratories have set up robust processes to provide evidence of the ongoing competence of their staff. This includes dip checking of a certain percentage of case work, internal open and blind trials, peer review, second and in some cases third checking of results/ fingerprint IDs etc. More importantly, the UK Accreditation Services (UKAS) (the UKs approved accreditation body (for ISO17025 and all other ISO standards) insist on all laboratories engaging in external proficiency testing before laboratory accreditation is granted. Where an accredited (to ISO17043) proficiency test scheme exists the laboratories must use it. The personnel part of the ISO17025 standard is robustly tested by UKAS and although the actual ISO17025 accreditation, when awarded, relates to the organisation/laboratory and not the individual the accreditation would not be given if the laboratory could not prove the competence of their individual staff.

Some laboratories tend to use proficiency tests as a test of individuals competency as well as testing the laboratory processes as they rotate the sample sets to different individuals each time they participate in the scheme or purchase additional sets of samples to test all staff at the same time. Such independent testing using actual samples for analysis rather than theoretical testing coupled with the strategies for testing individuals internally is the key to proving forensic competence in the UK. Within the UK Judicial System it is the Judge who decides who is competent/eligible to provide expert testimony. He/she bases this judgement on all of the above i.e. he/she will look at the accreditation status of the laboratory the individual works in, the processes the laboratory uses for testing competence internally of the individual, results of external accredited proficiency testing and the things the individual has done to maintain their competence and remain up to date with their knowledge e.g. CPD additional training/qualifications/commendations etc. If this is done robustly and an accepted standard set regarding desired outcomes and expectations so that confidence can be placed on an individual's ability to get the right result, then statistical presentations may not always be the answer.

Q3-2: How could well-designed performance testing be used more systematically for the above pattern based techniques to establish baseline error rates for individual examiners? What are the opportunities and challenges for developing and employing blind performance testing? What studies have been published in this area? The individual error rate of examiners is highly dependent on environmental and personal factors. Establishing a baseline error rate can be attempted; but it will never be an "exact science" or an accurate parameter for determining the reliability of the expert. This is because the error rate can greatly vary over time and is easily influenced by internal and external factors as any other employee can be. An examiner, regardless if his/her professional excellence and flaws is not comparable with a piece of equipment. Nonetheless, proficiency tests could provide an indication of the consistency and level of expertise of that

examiner. Ideally, in order to establish error rates, the tests should be "blind". However, I believe the application of blind testing in this specific case would not provide much more relevant information compared to non-blind tests if the examiner is a reliable professional.

David Brundage, Ballistics Laboratory Director, Aegis Sciences Corporation

Many of these tests are used to establish error rates, but unfortunately, made up tests are not the same as real and factual physical evidence. So, that while they approach or may indicate how a forensic examiner is performing, they can never completely leave out all biasness. The fields are improving, are more accountable, and continue to improve. Unfortunately, blind performance testing can never be complete accurate, b/c it is a manufactured test, it's impossible to make it completely fair and without bias. While there may be published studies on different performance testing, one would have to research and number of forensic publications and or journals.

Dr. Rachel Bolton-King, Award Leader for Certificates of Professional Competence & Lecturer in Forensic Investigation, Staffordshire University

Any type of test has the potential for testing bias to influence the prior expectations of the results and the potential outcome for firearm identification comparisons. There is a wide difference between proficiency testing and competence testing, with many people using the terms interchangeably and laboratories typically only undertaking internal and/or external proficiency testing. Proficiency testing only demonstrates the fact someone can undertake a skill, but does not assess whether they can perform this to a standard required within their job in the environment and time available to them. Further discussion can be read online in my publication relating to proficiency and competency testing in the UK firearms arena: http://eprints.staffs.ac.uk/1879/1/firearms%20comp.

Blind testing (ideally double blind testing) is a more appropriate demonstration of competence and would be the best way to evaluate potential error for individuals, but can be difficult to implement successfully (e.g. examiner may guess it may be a mock case) due to the collaborative input required from law enforcement, forensic laboratories and academia over a long period of time. A paper in press by Kerkhoff et al. (attached to this survey) is an example of such an effective double blind testing approach in firearms examination and also further discusses the opportunities and challenges for using in and details other research conducted in this area.

The topic of training, qualification and competence testing is also covered to some extent in the review article previously mentioned ('Preventing Miscarriages of Justice: A Review of Forensic Firearm Identification').

Carl C. Stacy - Director of Forensic Sciences/Chief Medical Examiner, University of Missouri Columbia, School of Medicine

The college of American Pathologists has surveys in these areas. As a physician I participate in CME continuously which includes some performance testing. Locally we have 100% peer review of all of our cases prior to completion. No report should be issued by just and individual without discussion and peer review. Quality improvement is best if it focuses on systems, documentation of findings and continuous improvement -- not individuals.

Bridget Lewis - President, International Association for Identification

In performance testing, the test provider needs to know the ground truth of the source of the impressions/images/objects. These tests are given throughout training, at the end of training, and throughout the career of the examiner. Also, certification testing is also available for examiners in many disciplines. Performance testing is used within laboratories to assess the conclusions in conjunction with Quality Assurance/Quality Control programs within the laboratories. Most performance tests are not

administered in a blind manner.

The challenge of testing is determining whether the questioned and known impressions/images/objects have sufficient data to determine different sources of origin or same source of origin. If these impressions/images/objects are insufficient, which inconclusive decision is correct? Determining the 'correct' or forensically appropriate decision when the data in impressions/images/objects is near or below the sufficiency or decision threshold is very difficult, even when ground truth is known. For example, if the ground truth is the two impressions/images/objects are from the same source, but the data is insufficient, the correct answer is inconclusive. But, what level of inconclusive is most correct? The near the sufficient threshold decisions are the most difficult to determine correctness of answer for a test. As each impression/image/object varies in appearance and varies in the available levels of details of data, predetermining the correct answer between same source and inconclusive, or, different sources and inconclusive, or, which inconclusive within a range of inconclusive is correct, is difficult to predetermine before a test when that decision comes from data near a decision threshold.

Another challenge of testing is determining whether examiners are restricted to answer based on their laboratory's protocols. Although professional guidelines exist, a laboratory may choose to have a more conservative approach for specific types of examinations and dictate what their examiners may or may not conclude. For example, some laboratories mandate that an exemplar shoe or tool must be present to make particular judgments. Additionally, an evidence photograph may not include a scale or may not be parallel to its subject, which could nullify its use. And, an examiner may determine an impression or object to be excluded as having been made by the known source, but, the reported answer may have to be inconclusive if there are not specific class characteristics present (e.g. anchor points in a fingerprint). These types of restricted judgments may affect error-rates if derived from particular tests.

A problem with determining baseline error-rates for individual examiners is answering the question, are these error-rates for all examinations or for this particular examination by an individual examiner? Error rates for all or specific examinations are difficult to determine, especially when dealing with decisions made at or near the judgment threshold of sufficiency and insufficiency for a particular conclusion.

Another question to consider is what constitutes an error? Is an inconclusive decision an error? What if the inconclusive decision is on the wrong side of the ground truth threshold, such as, the impression could have been made by the tool, but in reality, had not been made by the tool? The data of the details of repeatable features agree, but the details of unique features are insufficient to determine actual same source or different sources of origin. What if the 'forensically correct' inconclusive decision should be nearest the same source of origin decision, but the examiner chose the most neutral inconclusive decision available?

Determining meaningful error-rates for individual examiners will be an extreme challenge. Plus, if determining meaningful error-rates for 'traditional' forensic examiners is required, meaningful error-rates for all sorts of forensic experts, such as accountants, engineers, psychiatrists, psychologists, sociologists, and accident reconstructionists should also be required.

Blind testing is not currently required in forensic science. Before it becomes required, justification for that requirement should be provided. Blind testing has limitations in that the items being examined must have the same data available for all the examiners being tested. This is often attempted through the use of photographs so that many images that propose to show the same data are provided to the test takers. Often, these photographs do not appear to be normal case impressions/images/objects. Challenges of blind

testing include making the test appear as actual evidence and not a test.

Blind review of impressions/images/objects and conclusions reached can be conducted in casework. However, ground truth of the source(s) is not known for determining an error-rate. Rate of reaching the same conclusion or a different conclusion as another examiner can be accomplished with blind review of casework, but, the ground truth is not known and these error-rates would still have questions that need answered, such as, what is the most forensically correct answer?

It is important to note in regards to this question that it must be understood that the reliability and validity to be tested must refer to what is a forensically appropriate answer, not necessarily just as related to 'ground truth' of the source of the impression. For example, identifying a low quality and low quantity impression to a specific source may not be appropriate given the data in the evidence, even if the researcher knows the impression was made by that particular source object.

In an effort to provide the same data for known source impressions/images/objects, NIST has developed a standard bullet and cartridge case to QC the various NIBIN workstations around the country/world.
1.http://www.nist.gov/manuscript-publication-search.cfm?pub_id=905846
2.http://www.nist.gov/forensics/upload/vorburger_srms_AAFS_J21feb14-3.pdf

A survey of forensic labs would have to be taken to determine how common blind examinations and re-examinations (verifications) are being conducted. For blind and other examinations, laboratories must keep statistics regarding 'correct' or 'incorrect' determinations, or forensically appropriate decisions. One challenge for employing blind performance testing is that many units within labs are small, some only have one or two examiners, so coordinating blind re-examinations would certainly be challenging. If developing blind examinations and re-examinations that can be employed nationwide, there would have to be consensus as to which variables to control.

Sue Pearring - Senior Criminalist, Los Angeles County Dept of Medical Examiner-Coroner

Performance testing (PT) is currently done rather haphazardly from lab to lab. The role of PT can be for the actual testing process, the laboratory process as a whole, or the QA program in a lab. Depending on how these PT samples are introduced to a lab's testing program, the ultimate role of PT varies. For non-pattern-based techniques, clarity and thoroughness on the PT organizers' part can help standardize the role and thus usefulness of PTs. For pattern-based techniques, again, this is not my area of expertise.

Who is vested in the PTs and who is running them? Are the laboratories more worried about scoring high or about truly assessing their laboratory's shortcomings?

Paul L Morrow - Forensic pathologist, Auckland, NZ, formerly Chief Medical Examiner, Vermont

Performance testing is based on peer review and the standards of the practice of medicine, specifically forensic pathology, such as those published by the National Association of Medical Examiners

Eoghan Casey, Multiple titles and affiliations related to digital forensics and cyber investigation

Performance testing is important but cannot cover every context and circumstance involving digital evidence. One of my areas of research interest is developing a database of digital traces (patterns) that are commonly misinterpreted. Such a database could be used to train forensic examiners to be alert for such misinterpretations, and could be used in automated processed to alert forensic examiners when such patterns are detected. For instance, even experienced forensic examiners have misinterpreted as backdating digital traces caused by File tunneling and File Initialization in Microsoft Windows.

Some certifications have specific proficiency or performance tests. Most such tests are known to be a test by the examiner, and as such will not really provide a true test of error rate. Blind proficiency testing might be effective in digital forensics, but would be costly. As such, blind proficiency testing might only be feasible for large digital forensic laboratories.

Proficiency testing is just a small part of quality assurance in digital forensics. A comprehensive approach is need to detect and reduce errors, and to improve quality and professionalism. It could be beneficial for forensic science to adopt approaches used by healthcare providers or certified public accountants to manage quality and professionalism.

Deion P. Christophe, Firearm Examiner III/Section Supervisor IFL/NMS Labs

Many laboratories utilize what is known as a proficiency examination. These are routinely purchased by a third party vendor and issued to the examiner or analyst and asked that they be worked as casework. While these examinations are conducted in a blind fashion the examiners typically know that they are proficiency exams based on how they are administered or packaged. Other laboratories issue competency examinations in addition to the proficiency exams. In this instance, an examiner or analyst is not aware of the conditions of the exam and truly receives this as casework. This is worked as a blind study and will go through necessary peer and tech reviews as prescribed by the laboratories SOP. All of these tests could be designed to get more realistic baseline error rates for examiners. The task is simple; it begins with the submission process and how the case is presented. The opportunities and challenges for developing these examination in a truly blind fashion will continue to exist over time, however with consistency in the way they are administered, along the lines of routine casework, it is believed that an established error rate can be recorded.

Professor Sue Black and Professor Niamh NicDaeid, Professors at CAHID, University of Dundee, UK

This is more of an operational question. Ground truth databases could be used as training and testing tools. An agreed mechanism for testing should be encouraged to ensure a consistency across laboratories, practitioners and indeed countries. It should be encouraged that this form of testing is not designed by those who will be tested but is designed and implemented by impartial and unbiased standards authorities.

Michele Triplett, Forensic Operations Manager-King County Regional AFIS

Performance Testing Performance testing currently assesses the examiners ability to get the accurate conclusion but does not assess the reasoning behind the conclusion. This means that accurate conclusions arrived at inappropriately are still considered correct. Since the ground truth is never known in casework, it is impossible to determine the accuracy of a conclusion. The appropriate way to measure conclusions based on logical reasoning is to assess the support (the ambiguity and amount of data) behind the conclusion to determine if the conclusion is well supported. Performance tests for the pattern evidence disciplines need to start assessing the support behind the conclusion instead of only assessing the conclusion. This is similar to testing math problems where both the conclusion and the reasoning behind the conclusion are graded (only stating an answer would not be acceptable on a math test). Any research, competency test, or certification test that is assessing conclusions, without looking at the reasoning behind the conclusion, is missing the key element.

Before the logic behind a conclusions can be assessed, acceptable principles and the acceptable criteria for conclusions need to be determined. Currently, the criterion for a conclusion is ‘get the correct answer’ but HOW to do that is not defined. It is usually stated as ‘look for consistency and inconsistency in the features’, but the amount of consistency/inconsistency is based on the tolerance level of each practitioner. This is

unacceptable; a criterion needs to be stated (even if the criteria is to ensure the support behind conclusions holds up under rigorous scrutiny). If acceptable principles and a criteria are not stated, then it is impossible to determine if the logic is correct (e.g., the method of long division has been determined, it is then taught to students, and then they are tested to ensure they are performing long division in an appropriate manner). The rules to arrive at pattern evidence conclusions are vague at best. They need to be well defined and taught PRIOR to testing examiners and prior to spending millions of dollars on error rate studies.

Blind Testing The use of blind testing sounds persuasive; however, it again focuses on the conclusion and ignores the most important element, the support behind the conclusion.

Xhemajl Ademaj, Fellow American Academy of Forensic Science

It is evident that the performance of testing in forensic laboratories , connected with the work of experts is performed with a qualitative tolerance excessive where based experts in these performances have come down to mistakes therefore possible performance conducted by leader has to be in harmony the work of the expert.

Michael T. Beddow, Forensic Scientist IV, Phoenix Police Department Crime Laboratory

Performance testing is conducted in several different ways:

1. Competency testing: tests provided to Forensic Scientists prior to beginning casework in a specific sub-discipline to ensure that the individual is competent to perform that type of analysis.
2. Annual proficiency testing: tests that are provided annually to Forensic Scientists, for quality management and accreditation purposes, in order to verify that an individual is still proficient to perform the types of analyses tested.
3. Quarterly case work re-analysis: As part of our Quality Management System one case completed by each Forensic Scientist is reanalyzed by another Forensic Scientist once per quarter. For this purpose the original examiner has no knowledge or input into which cases will be chosen for reanalysis.

None of the above listed "performance testing" methods can be considered blind or double blind as the all Forensic Scientists are aware when they are being given the test. At the current time these methods are the best and most practical ways to test the "performance" of practicing Forensic Scientists.

Due to legal and policy issues at local, state and even the federal levels I do not believe that it would be possible to create true blind and especially double blind performance tests for practicing Forensic Scientists. These types of tests would require the creation of fictitious requests for scientific analysis within computer systems and databases that are controlled by government agencies with policies that strictly prohibit their use for any activity other than official use.

Brandon Giroux, President, Association of Firearm and Tool Mark Examiners (AFTE)

Angela Stroman, in the "Declared vs. Blind Testing" section of her recent research paper entitled "Empirically Determined Frequency of Error in Cartridge Case Examinations Using a Declared Double-Blind Format" AFTE Journal, 46(2), Spring 2014, pp. 157-175, did an especially cogent job of describing the current status of proficiency testing in firearm and toolmark identification, and for that reason, it is attached in its entirety."

American Academy of Forensic Sciences (AAFS) Board of Directors

The most widespread performance testing is done via annual and bi-annual proficiency tests administered by test providers, including, but not limited to, Collaborative Testing Services (CTS), the International Qualifications Assessment Service (IQAS), the College of American Pathologists (CAP), and Forensic Testing Services (FTS). Other performance tests come from volunteering to participate in skill assessment based

research projects. On the other hand, proficiency testing may also be an individual requirement for certain certifications, particularly by the American Board of Criminalistics (ABC). Most proficiency tests are open proficiency tests in which they are known to be proficiency tests by the analyst conducting the test; therefore, the process has been criticized by some as a poor test/ measure of error. Blind proficiency tests have been successfully performed in large labs, but they are expensive and less likely to remain undetected as a proficiency test in smaller laboratories—particularly where the analysts and detectives know each other. Robert Gaensslen and Joe Peterson published their NIJ-funded study on this point. The USACIL laboratory, a large laboratory, is studying blind proficiency testing. Regardless, proficiency tests are not good measures of error rates. They are taken too infrequently to be a satisfactory measure of error. Most proficiency tests are not designed to be challenging, because they are regulatory in application and supposed to demonstrate that an analyst can obtain correct results. Educational challenges are superior in improving skills in the community, precisely because they are not regulatory. Lastly, incorrect proficiency tests should provoke a quality assurance response that should result in the error not recurring. The query should not be about individual analyst performance, but about detecting and reducing errors.

Jill Spriggs, President, CA Association of Crime Lab Directors

Performance testing occurs through competency testing (the testing of a new examiner in a method or type of analysis, to show that the individual is competent to perform casework of that type). Performance testing also occurs through proficiency testing, which occurs annually for examiners in a given discipline, and twice per year for examiners performing DNA analysis. Proficiency tests are not geared toward developing error rates by an individual. Proficiency tests are conducted to test the laboratory, and for that reason proficiency tests are technically reviewed by another examiner prior to being released. Laboratories are encouraged to establish a proficiency program that mirrors casework, including the technical review step. As a result, it is to be expected that an error in a proficiency test would be corrected in the laboratory before the answer is submitted to the testing agency. The laboratory's quality system would then deal with the analyst who made the error, perhaps through re-training and additional testing. The relatively few proficiency tests completed by an examiner in a given discipline do not constitute a sufficient number to allow a calculation of individual error rate.

Blind proficiency testing has been used to a limited extent in some disciplines in some laboratories, but the amount of time required to set up and administer a system of blind testing is prohibitive. It requires coordination with local law enforcement to attempt to simulate actual criminal casework, and it can be expected that savvy examiners will be able to detect that a case is actually a blind proficiency rather than real casework. Most laboratories have reached the conclusion that it is not worth the time and effort to establish blind proficiency testing. The idea of developing individual error rates from blind testing of examiners is folly. Several hundred exams would be required to be given to each examiner (too time consuming), and in a blind fashion (not realistic).

Randy A. Sandifer, Forensic Scientist, American Academy of Forensic Sciences

Performance testing or CTS testing is a major factor in forensic testing. Within forensic testing blind testing is essential to the overall integrity of the forensic field.

Matt Johnson, Orange County Sheriff's Office, OSAC Footwear/ Tire Track Subcommittee

How is performance testing (testing designed to determine the frequency with which individual examiners obtain correct answers) currently used in forensic laboratories?

There are several Proficiency Test providers who are approved by the American Society of Crime Laboratory Directors/Laboratory Accreditation Board such as Collaborative Testing Services, Inc., Forensic Assurance, Forensic Testing Services and Ron Smith and Associates who providence proficiency testing in

Footwear and/or Tire Tread analysis. Additionally, Forensic ITC Services, although not listed with ASCLD/LAB is also a proficiency test provider. These tests are prepared to simulate case work that laboratories and examiners would receive. Proficiency tests are designed to assess the performance of the footwear and tire tread examiners. They can be used as a training tool, to demonstrate competency of a newly trained examiner and to demonstrate the ongoing proficiency of the experienced examiner. If the test is used as performance testing the individual examiner results are reported to the test provider who compiles the results and issues a report to the participants. The report includes the frequency of the conclusions for each of the questioned impressions as reported by the participants.

Are performance tests conducted in a blind manner?

There are no requirements through the test provider or through ASCLD/LAB to conduct the examination or verification in a blind manner. The original examiner does not know the results or ground truth of the comparisons. A verifier may know the conclusions of the original examiner; but neither is aware of the conclusions specified by the provider.

How could well-designed performance testing be used more systematically for the above pattern-based techniques to establish baseline error rates for individual examiners?

Forensic Assurance states that "the proficiency test answer sheet, when combined with participant information, can be used to calculate statistics relevant to the forensic science and legal communities. Forensic Assurance collaborated with statisticians from the University of Michigan to develop statistical models to calculate false positive and false negative error rates, as well as sensitivity and specificity. This statistical information will be available for practitioners to use in admissibility hearings". Some test providers, such as Collaborative Testing Services, Inc. had not intended for the test results to be used to estimate baseline error rates of footwear examiners. Collaborative Testing Services, Inc. places the following statement on their website to address using information compiled from the completed proficiency tests: "all information presented in this site is intended for the non-commercial use of CTS' Interlaboratory Program participants. The use of information obtained through this site to establish independent data files or compendiums of statistical information is prohibited." The proficiency tests can be purchased by any lab and does not require that the examiner have specified training to take the test. Collaborative Testing Services, Inc. does not collect information regarding the individual examiners who complete the test nor consider why the tests are being purchased. "Using CTS proficiency test results to determine an error rate would therefore not necessarily reflect the standards of examinations used in casework since the results do not consider the participant-directed employment of the testing and examiner demographics." Considering this, proficiency test should not be used to establish baseline error rates for examiners as a whole.

In order to incorporate the results of proficiency testing to establish baseline error rates for individual examiners more information would need to be provided regarding the use of the test, the level of training and experience of the examiner completing the test and the test would need to be reviewed by trained examiners to compensate for the variability in stating results. Impression evidence results are not always clear cut in actual casework but must be supported through documentation.

What are the opportunities and challenges for developing and employing blind performance testing?

Challenges of incorporating blind verification would be the impact of casework and the limited number of examiners per agency who are trained in footwear and tire track examinations. The examiner conducting a blind verification would essentially "rework" the case of the initial examiner. This work is time consuming and an agency would need to be properly staffed to complete blind-verifications.

What studies have been published in this area?

Some studies have been done to assess between-examiner variability in footwear examinations (Majamaa & Ytti, 1996, Hammer et al., 2012, Kerstholt et al., 2006); even in these studies, the examiners were aware that their performance was being observed. As such, neither the results from the proficiency tests nor the research studies should be taken as representatives of actual error rates of examiners.

Since there is no ground truth in actual casework, it would not be feasible to correlate or make inferences regarding the significance of the proficiency testing data and apply it to real-world cases. In this regard, it may be useful to adopt data mining techniques for characterizing and analyzing the decision making process and outcomes, which are already in use in other fields such as airline customer relationship management (Liou, 2008), fault diagnosis in engineering (Yam et al., 2001), bankruptcy risk assessment, etc. (Greco et al., 2002; McKee and Lensberg, 2002).

New Technology

Question 4 – New scientific techniques

What are the most promising new scientific techniques that are currently under development or could be developed in the next decade that would be most useful for forensic applications? Examples could include hair analysis by mass spectrometry, advances in digital forensics, and phenotypic DNA profiling.

Steven Johnson, Board Chair - The International Association for Identification

As far as latent print examination is concerned, the research into probability modeling shows the most promise.

C. Michael Bowers, odontologist. Ventura Medical Examiner

Dentists provide valuable assistance in the identification of unknown human remains. My hope is that Missing and Unidentified management systems controlled by law enforcement will overcome problems with reporting non-compliance and NCIC software that is largely ineffective regarding dental information.

Frederick R. Bieber, Professor, Harvard Medical School

Rapid DNA testing, Next-generation DNA sequencing, video and audio forensic surveillance systems, facial contour recognition methods, phenotype prediction using DNA

Mary Beth Hauptle, Forensic Odontologist, FCMEO

Phenotypic DNA profiling will always "trump" a bite mark pattern injury in validity and reliability.

Melissa Connor, Director, Forensic Investigation Research Station

I would say the statistical methods of evaluating biometrics such as fingerprints.

Tatiana Maria Blanco Alvarez, MA, Graduate student TTU

Nail polish and lip gloss analysis by mass spectrocopy (lopez, Vas & Garcia, 2015; Zellner & Lawrence, 2009) Studies in entomology (De Jong, 2014) And right now there are fields like forensic anthropology, forensic chemistry, forensic engineering that are developing protocols and techniques that can be used to obtain evidence.

Femblix Meek Tom Jr, Student Citizencorps.gov AAFS.ORG Fvtc.edu Dna.gov Wvu.edu Bronx Community College

Working on crime lab has an individual sometimes failed the report why sharing learning center agency affiliated improved the basic impact has a professional development forensic science DNA fingerprinting, one of the great discoveries of the late 20th century, has revolutionized forensic investigations. This review briefly recapitulates 30 years of progress in forensic DNA analysis which helps to convict criminals, exonerate the wrongly accused, and identify victims of crime, disasters, and war. Current standard methods based on short tandem repeats (STRs) as well as lineage markers (Y chromosome, mitochondrial DNA) are

covered and applications are illustrated by casework examples. Benefits and risks of expanding forensic DNA databases line analysis

Pierre Margot, Emeritus Professor University Lausane

Techniques are only tools. New tools can always be useful, but will not replace the knowledge base necessary for interpretation behind techniques. Many claims regarding new technologies do fail in the long run, failing to address the difficult forensic science questions.

Mark Leney, Professor, UMass Medical School and Deputy Director, MassBiologics

I think that deep-sequencing or massively-parallel sequencing has potential to advance the analysis of degraded or contaminated evidence and will become a key tool.

Eric Warren, Ph.D., Special Agent/Forensic Scientist, Tennessee Bureau of Investigation

One of the most promising scientific techniques in FA/TM ID is the use of 3D surface examinations. By producing (via imaging or tomography) a 3D representation of the surfaces examined, one can develop algorithms and set thresholds to make the science more objective and rely less on individual examiners to make a determination call. While I do not feel there is anything wrong with the examiner making a subjective call (this is done all the time in many medical disciplines – radiography, dentistry, physical therapy, chiropractic care, even by a primary care physician diagnosing a symptom), having a standard determined mathematically can only improve the field.

Heather Edgar, Associate Professor, Curator, University of New Mexico

Comparative analyses and large databases of CT and MRI scans.

Robert Gaensslen, Prof Emeritus, Univ of Illinois Chicago

Hair analysis as I understand it has some problems. Saliva has some possibilities. (Talking about drugs here). Digital will become crucial. Handwriting will be dead in a few years. No one will 'sign' their name or write. Phenotypic DNA profiling would be useful in unknown subject cases (which BTW, is a minority of cases), but there are privacy issues here, especially if you start looking at disease or medical-condition genes. These approaches might be more useful as investigative tools than as testamentary evidence.

Dr. Sushil Kumar Sharma, Editor, EC Chemistry, UK

Dr. Beauchemin (Chemistry) and student Lily Huang (MSc'15) have developed a cutting-edge technique to identify human hair in Queen's University using spectroscopic method. Their test is quicker than DNA analysis techniques currently used by law enforcement. Early sample testing at Queen's produced a 100 per cent success rate. Blood samples are often used to identify gender and ethnicity, but blood can deteriorate quickly and can easily be contaminated. Hair, on the other hand, is very stable. Elements in hair originate from sweat secretions that alter with diet, ethnicity, gender, the environment and working conditions. " This analysis process is very robust and can be used universally," says Ms. Huang. "One of our samples even included dyed hair and the test was 100 per cent accurate. The test was able to distinguish East Asians, Caucasians and South Asians."

Edward Imwinkelried, Edward L. Barrett, Jr. Professor of Law Emeritus, University of California Davis

Microbial analysis has great potential. Stessy, Eisen, Imwinkelried & Vandamme, Microbial Forensics: The Biggest Thing Since DNA?, 51 Criminal Law Bulletin 726 (2015).

Moses S Schanfield, Professor, Department of Forensic Science, The George Washington University

Digital forensics is a biggest possible growth area. Phenotypic testing would be useful, but it is at best probabilistic and an investigative tool. Leading to the need for guidelines in the interpretation of this material. New advances in drug analysis are needed as the array of synthetic and designer drugs increases in frequency and sourcing of these drugs has a broader base than historically. Fortunately, there appears to be development of new instrumentation to support this.

Abigail Lehman, Criminalist III, Missouri State Highway Patrol

GCIR for the determination of isomers for synthetic cannabinoids. The current technology is not easy to use.
LCMS for qualitative and quantitative analysis of drugs. Current instrumentation is too sensitive for many methods.
Easier methods for separation of drugs in mixtures for isomer confirmation.

Rigo Vargas, QD Section Chief, MS Forensic Laboratory

1. Role of Automation in the Forensic Examination of Handwritten Items, Sargur Srihari Department of Computer Science & Engineering University at Buffalo, The State University of New York
2. D-Scribe - Automatic Authorship Identification and Clustering, Siemens AG
3. Writer Recognition by Computer Vision, Jeffrey P. Woodard MITRE CORP Christopher P. Saunders MITRE CORP & South Dakota State University Mark J. Lancaster USG
4. FLASH ID Forensic Language Independent Analysis System for Handwriting Identification
5. Write-On 2.0, Pikaso Software, Inc.
6. Isotope ratio mass spectrometry as a tool for source inference in forensic science: A critical review.

Marianne Stam, Retired (in 2015) Criminalist Supervisor

Consolidation of existing and development of new nationwide or worldwide databases in which the data is placed in searchable Geographic Information System (GIS) formats and used for sourcing/provenancing of trace evidence (e.g. soils (and related materials such as pollen and botanical evidence), automotive carpet fibers/automotive paints etc...). Many databases exist but they are either inaccessible to the general forensic community (but should be more accessible); their existence is unknown to the forensic practitioner, or they are not easily found because there are too many repositories for the data.
Also, Isotope Ratio Mass Spectrometry is being applied to Forensic Science more in Europe than in the United States - but it shows promise in forensic science and should be explored more here in the US and made more user friendly and economically feasible.

Michael Kusluski, Forensic Scientist, Michigan State Police

We can't extricate ourselves from these problems simply by creating new techniques. Despite what many critics have said, the problem is not a lack of scientific validity, but a lack of uniform training and oversight. There are very good labs and there are very bad labs. This needs to be addressed first. But unfortunately, this isn't as newsworthy as a shiny new gadget.
But as far as technology is concerned, I would spend money on automation first, to reduce backlogs, improve reliability and minimize errors during tedious processes.

Daryl Belock, VP, Innovation and R&D Collaboration, Thermo Fisher Scientific

One area we've explored is the opportunity to migrate laboratory methods to the field in portable / handheld form factors. An example of this is our TruNarc product which uses raman spectroscopy which classically has been uses as a laboratory technique. Our application for TruNarc has focused on drug testing. This is disruptive to tradition NIK kit colorimetric testing, but could also be directly used as a confirmatory test given the accuracy, specificity and performance of such technology using modern technology. In terms

of validation, the device integrates a polystyrene test piece as a cover for the nose cone which can be used as a validation sample before and after each test as part of field workflow to confirm instrument functionality.

We've explored other adaptations of raman technology to field based forensics studies, but have not moved to commercialization. This has been principally involving the use of SERS (Surfaced enhanced raman spectroscopy) particles to enhance sample sensitivity for applications such as blood sample ID (male vs. female; human vs animal) at the crime scene where the principal benefit would be more timely information available to investigators.

James DiFrancesco, Forensic Biologist/ U.S. Army Criminal Investigation laboratory

Continuous probabilistic genotyping models like STRmix, RNA body fluid identification, and next generation sequencing.

Dr. L. Thomas Johnson, Professor (Retired) Marquete University

Advances in automation of digital image analysis and pattern recognition.
Further development of the geometric application of intersecting angles applied in the must recent research report - "Replication of Known Dental Characteristics in Porcine Skin: Emerging Technologies for the Imaging Specialist NIJ 2010-DN-BX-K176"

Chris House, Program Support Manager - National Forensic Laboratory Services

High resolution mass spectrometry with exact mass of parent and fragment ions. More labs are adopting this technique especially in toxicology but also chemistry/trace analyses.

Maciej J.Bogusz, MD, PhD, Prof.of Forensic Toxicology em.

As applied for forensic toxicology, most useful technique both for identification and quantitation of toxic compounds is ultrahigh-performance liquid chromatography coupled with high resolution mass spectrometry. As mass spectrometer most useful is tandem-MS, QTOF, or orbitrap. However, the most promising technique for the future ismolecular imaging by mass spectrometry (MSI, which enables detection of drugs and other compounds in aitu, without isolation from the biological matrix. The research in this direction should be mostly supported.

Michael A Wagner, Indiana University Purdue University

The redesigning of the mass spectrometer from a full size table top design to a hand held design. This could revolutionize point of care testing in clinics and addiction centers by bringing tests results closer to the patient/physician diagnosis. With respect to addiction this will facilitate better care/compliance. The same will go for drug courts and probation monitoring. Also the continued application of oral fluid testing for toxicological analyses. Expanding this in the drug impaired driving discipline as well as developing oral fluid testing for alcohol. Oral fluid alcohol represents very closely alcohol concentration found in blood. Again the availability of this matrix will allow for forensic evidence to be collected at the time of the incident. It also allows the individual access to an independent sample that may be test at a facility of their choosing to be used as evidentiary information on their behalf.

Dr. Geoffrey Stewart Morrison, Independent Forensic Consultant; Adjunct Associate Professor, Department of Linguistics, University of Alberta

The problems in forensic voice comparison are not at this stage primarily technological, they are primarily the lack of relevant databases, the lack of understanding of the logically correct framework for the evaluation of evidence, and the lack of empirical testing of validity and reliability under casework conditions. Lack of understanding of the logically correct framework and lack of understanding of what constitutes

appropriate testing affects all branches of forensic science, and is widespread among forensic scientists, lawyers, and judges. Current priorities need to be database collection and training, not new technology.

Glen Jackson, West Virginia University

Yes, chemical hair analysis is a very exciting and promising new area. New Mass spectrometry capabilities are enabling us to examine the drugs and metabolites in hair, the proteome expression in and of the hair, teh geographic provenance of an individual, and classification into characteristic traits such as body mass index, sex and age group.

I would add that stable isotope ratio analysis is an exciting new area that demonstrates the ability to link or exclude source material at an unprecedented level.

Josep De Alcaraz-Fossoul, Researcher and Assistant Professor, University of Barcelona

There are numerous scientific techniques that are being developed and tested for forensic purposes. One of the solutions to improve the reliability of forensics will be the ability to determine the aging process of evidence. I believe this holds one of the keys to minimize misattributions and wrong sentences.

Angi Christensen, Forensic Anthropologist, FBI Laboratory

In forensic anthropology, the analysis of radiologically-varied traits has been facilitated in part by advances in forensic imaging (such as CT) as well as associated software for volume rendering, measurement, etc.

Darrell O. Ricke, PhD, Massachusetts Institute of Technology Lincoln Laboratory

High Throughput DNA Sequencers (HTS) now enable massively parallel characterization of 10 to 20 thousand Single Nucleotide Polymorphisms (SNPs) on trace DNA forensics samples. This data enables identification (ID), comparison and analysis of complex DNA mixtures of from 2 up to 20 contributors, and kinship determination. These capabilities will have a major impact on DNA forensics in the next decade.

Isaacson, J., et al. Robust detection of individual forensic profiles in DNA mixtures. Forensic Sci. Int. Genet. 14:31-7 (2015).

Ricke, D. et al. Sherlock's Toolkit: A Forensic DNA Analysis System. IEEE Technologies for Homeland Security, 2015.

David Brundage, Ballistics Laboratory Director, Aegis Sciences Corporation

My opinion is that digital developments in the field of firearms/toolmarks will have a greater effect in forensic laboratories. Instrumentation and its application to current identification techniques will continue to improve. It's ability to assist the forensic scientist to do a better and provide a more thorough examination of physical evidence.

Dr. Rachel Bolton-King, Award Leader for Certificates of Professional Competence & Lecturer in Forensic Investigation, Staffordshire University

Within the firearms arena, the development and application of statistical models/algorithms, which objectively interpret 2D data and 3D data gathered by imaging systems to support conclusions (elimination, inconclusive or identification) formed by practitioners when comparing patterns such as toolmarks, fingermarks etc.. Within my international research group, Deion Christophe (Texas, USA) is currently aiming to develop and employ such an approach as the focus of his PhD research.

I have been developing the application of security-based x-ray analysis to non-destructively examine corroded and seized firearms that have been buried or submerged for extended periods of time. This technique can establish the safety and function of the weapon, estimate the calibre and evaluate the potential value of forensic evidence in situ at the crime scene, informing forensic strategy and submission of

the weapon to the laboratory. This approach has also been applied to weapons stored and displayed in military museum collections and has potential impact in other arenas too.

Carl C. Stacy - Director of Forensic Sciences/Chief Medical Examiner, University of Missouri Columbia, School of Medicine

All could be useful if peer-reviewed and well done.

Joseph Prahlow - Professor of Pathology; Forensic Pathologist – Western Michigan University

From a forensic pathology standpoint, I see 2 major areas:

1) imaging technology (quick-scan radiology, such as LoDox, CT scans, and others). FP facilities, particularly those that are involved in education, MUST have such technology in the future.
2) Molecular testing. The "molecular autopsy" (performing molecular/DNA testing in order to detect underlying genetic causes of sudden death) is one of the things that will eventually become standard. More funding to develop panels for testing would be helpful.

Bridget Lewis - President, International Association for Identification

Technology searches of databases could be most useful for incorporating into the examination process. Generating meaningful scores from these searches for the published candidates should help. Support for developers of better algorithms should be provided.

Providing technology for more closely and accurately viewing the impressions/images/objects could help. Using computer technology to better understand human vision. Extracting more details from the available data in impression/images/objects could help. 3-D Scanning Confocal Microscopy for conducting comparisons of tool marks and fracture match evidence is a consideration. Technology that assists in the analyses and comparisons of details should be developed. Studies should be conducted on the effects new technology has on the conclusions that are reached.

Some technology can be found in the following links:

1. https://www.ncjrs.gov/pdffiles1/nij/grants/248639.pdf
2. https://www.ncjrs.gov/pdffiles1/nij/grants/248962.pdf
3. http://jjcweb.jjay.cuny.edu/npetraco/tutorials/CADOJ_14_workshop_petraco.pptx
4. https://www.forensiccoe.org/Our-Impact/Advancing-Technology/Reports/Forensic-Optical-Topography-Working-Group-Meeting-Final-Report
5. https://www.forensiccoe.org/LinkClick.aspx?link=https%3a%2f%2frti.connectsolutions.com%2fp2isay529wa%2f&tabid=175&portalid=0&mid=829
6. http://search.usa.gov/search?affiliate=national-institute-of-justice&page=1&query=pattern+recognition
7. http://www.nist.gov/itl/iad/face-060314.cfm
8. http://vision.soic.indiana.edu/
9. http://vision.stanford.edu/
10. http://www.nist.gov/oles/upload/-12-Sargur-Srihari_CEDAR-FOX-iFOX-NIST2013-RoleAutomation.pdf or http://www.cedar.buffalo.edu/~srihari/
11. http://www.nist.gov/oles/upload/D-Scribe-Schulte-Austum_2013-MSSFHA-Conference.pdf
12. http://www.nist.gov/oles/upload/-14-Jeffrey-Woodard-SIFT-Writer-Recognition-by-Computer-Vision-final.pdf

Beyond technology, better understandings, documentations, and explanations of the forensic comparative examination process should also be pursued.

Better understanding of the human mind should be developed through cognitive psychology and vision science studies. How examiners visually and mentally process data should be studied using cognitive psychology research, such as found in:

1. http://cognitrn.psych.indiana.edu/busey/HomePage/pubs.htm
2. http://www.visionscience.com/

The studies of philosophies of science and logic should be brought into forensic comparative science. Philosophical explanations of how we know and believe our examination process should be pursued. There are many aspects of philosophies of science, as found in:

1. http://plato.stanford.edu/search/searcher.py?query=science
2. http://undsci.berkeley.edu/article/philosophy
3. http://www.worldcat.org/title/philosophy-of-science-the-central-issues/oclc/37955435

Sue Pearring - Senior Criminalist, Los Angeles County Dept of Medical Examiner-Coroner

While there are many new technologies available that can help progress the forensics field, I believe the greater priority as of today is the standardization of forensic techniques and increasing the robustness and understanding of current practices.

Paul L Morrow - Forensic pathologist, Auckland, NZ, formerly Chief Medical Examiner, Vermont

Advances in postmortem imaging and toxicology as supplements to the postmortem examination and autopsy process. Advances in medical laboratory (clinical pathology) techniques as applied specifically to the postmortem context

Eoghan Casey, Multiple titles and affiliations related to digital forensics and cyber investigation

Digital individualization - using digital traces to discern patterns that can be attributed to a specific individual with a high degree of confidence. Having just received my OPM breach notification on Monday makes me wonder how such breaches alter reliability of digital identity. My fingerprints and other PII be used by a malicious actor to masquerade as Eoghan Casey in cyberspace and the physical world.

In an effort to address this specific question, the DFRWS was established in 2001 to look ahead 1 year into the future. Every couple of years, we have a major breakthrough in digital forensics. In 2005, DFRWS participants motivated major advances in memory forensics. In 2006 and 2007, DFRWS participants motivated major advanced in file carving, i.e., salvaging deleted files that were previously irretrievable. In 2010 and 2011, DFRWS participants motivate advances in mobile device forensics, including mobile malware analysis. All of these developments will be useful in decades to come, continuing to produce useful forensic findings and supporting tools in 2015 and beyond. In an effort to extend the impact of digital forensic research, DFRWS is directing its resources and efforts into international collaboration and emerging technologies.

Deion P. Christophe, Firearm Examiner III/Section Supervisor IFL/NMS Labs

Forensic Optical Topography, however much is still unknown in this particular area of expertise and research. Recently a report was published regarding NIJ's work group meeting. In this report it was stated clearly that NIJ has been funding research in optical topography for over 6 years however, few state and local laboratories have taken the steps to implement such technology. While there are many systems in this arena, the troubling aspect seems to be finding one the fits all a laboratories needs based on evidence that is submitted. This is a huge undertaking for many state and local laboratories to invest in such instrumentation and then seek out multiple applications while pushing casework out the door. Funding is one difficulty but another is finding candidates to assist trained examiners in the application of such research. It is very apparent in the report that NIST and the FBI, with support from many other members within this working group, plan to work together in an attempt to validate these approaches and work towards an appropriate implementation procedure.

Professor Sue Black and Professor Niamh NicDaeid, Professors at CAHID, University of Dundee, UK

New technologies which could be employed into the forensic science ecosystem are limited by our imagination only. It is not what new technologies could emerge but more about ensuring that there is a requirement for a technological solution in the first place. We must first start by understanding the question, the value of that question to the case at issue and whether we have enough of a fundamental understanding of the value of particular evidence types to the judicial process. Taking hair as an example, we need to ask the basic research questions around what we are trying to achieve in hair analysis? If it is to assess whether physical morphological characteristics can aid in an identification of an individual, then we need to understand the variability within one individual and across individuals to merit the analysis in the first place. If the question is to identify where an individual may have lived, then Isotope Ratio Mass Spectroscopic analysis can already achieve this to some extent but we need to scientifically understand the boundaries of certainty around the measurements. If the question is about drug taking or exposure to volatile organic compounds associate with drug or explosive manufacture then chromatographic analysis can already achieve this again within already known analytical bounds.

New technologies are welcomed but must be grounded by robust scientific measurement and validation including the generation of appropriately sized ground truth databases so that the implementation of such techniques do not suffer from the legacy of poorly understood or absent scientific underpinning.

Xhemajl Ademaj, Fellow American Academy of Forensic Science

Using advanced technology, electronic scan microscope, atomic absorber, spectrometric mass, infra- red technology, using advanced kit for the extraction of DNA profiles , modern teaching technology of electrophoresis etc.

Michael T. Beddow, Forensic Scientist IV, Phoenix Police Department Crime Laboratory

Within the field of Forensic Firearm and Toolmark Examination the most promising new scientific technologies/techniques under development are 3D surface topography imaging systems. Currently all of these systems are being investigated in conjunction with varying forms of "ballistic imaging" databases. However, the imaging systems themselves, as standalone units, show great promise for assisting Forensic Firearms Examiners with the analysis of certain toolmark surfaces which analysis through traditional optical microscopy methods can be very difficult due to reflectivity issue with the working surfaces.

Andy Smith, Chair - Firearm/Toolmark Subcommittee NIST OSAC

The Firearms/Toolmarks subcommittee of the Organization of Scientific Area Committees (OSAC) has established a Task Group to study and evaluate the research and development of instruments and software

that can accurately measure and compare microscopic toolmarks and provide statistical weight to the comparison. This technology has the potential to provide greater objectivity and statistically-supported conclusions to the science of firearms and toolmark comparison. "

Tim Schellberg, President, Gordon Thomas Honeywell Governmental Affairs

One of the most exciting new scientific techniques on the horizon is the use of Next Generation Sequencing (NGS) for forensic DNA profiling. NGS has the potential to revolutionize forensic DNA programs. NGS provides the capability to capture more data faster, is more discriminatory, and will be a powerful tool in developing information from difficult forensic samples that may otherwise be missed with traditional STR DNA analysis methods. However, because NGS has the ability to sequence the entire genome, it will be important for the forensic community to collaborate on standards to ensure that our policymakers are comfortable that this new technology can be used responsibly without risks to privacy. In particular, the community may need to come to an agreement on which markers and ultimately which panels should be recommended. For example, markers that determine eye and hair color may be acceptable. But markers that identify more sensitive traits, or are predictive for disease, will likely be considered unacceptable.

Clifford Spiegelman, Distinguished Professor Texas A&M U

IR imaging. It is a heat based method that avoids shadows and glare. Recent technological breakthroughs make a shoebox size system possible at production costs of a few thousand dollars per unit.

Brandon Giroux, President, Association of Firearm and Tool Mark Examiners (AFTE)

There are currently no quantitative criteria widely utilized for the identification of toolmarks; however, within the past 5 years, there has been significant progress in this area through research in the optical topographical analysis of toolmarks. This is the most promising new technique in the area of firearm and toolmark identification.

The extent of progress in the optical topographical analysis of toolmarks was brought into sharp focus recently with the formation, by RTI International Forensic Technology Center of Excellence, in partnership with the National Institute of Justice (NIJ) and the National Institute of Standards and Technology (NIST), of the “Forensic Optical Topography Working Group”. The final report, dated April 17, 2015, on their March 17-18, 2015 meeting, is attached. In the “Overview” portion of this report, it is stated that “this working group seeks to establish the applicability and validity of optical topography to forensic investigations and to produce publications or training materials that can be accessed by the entire forensic community and that will provide guidance to practitioners on applications and recommendations for further research, development, and capacity assistance. Primarily, the working group will examine optical topography instruments, methods, data systems, and analysis from a practical perspective for ballistic and tool mark identification.”

American Academy of Forensic Sciences (AAFS) Board of Directors

On the DNA-side, one can point to the potential use of next generation sequencing for genotyping. This is a method that if implemented will make the use of electrophoresis to separate PCR products obsolete. There is also great hope for mRNA, microRNA, and DNA methylation methodologies to be used for body fluid stain identification, which may allow for a single molecular extraction for both body fluid stain identification and genotyping. STR multiplexes are also increasing the number of core loci, which may help alleviate some of the concerns surrounding familial DNA searching. Finally, the use of computer-based continuous methods may lead to a consensus probabilistic model for DNA mixture interpretation.

It is also possible that the Criminalistics community may see the effects of Raman spectroscopy for both biological and chemical analyses. Although the technology is not as high profile as its counterparts in the

molecular biological realm, Raman has been shown to be useful in body fluid stain identification and in the analysis of many types of trace evidence. Additionally, the further advancement of spectroscopic methods that eliminate the need for sample preparation (e.g. laser ablation, infrared spectroscopic imaging) may be implemented in crime labs.

In the area of question document examination, examiners may see an increased role of automation as a tool in the examination of handwritten items and the use of Isotope Ratio Mass Spectrometry as a possible use for source inference, especially papers and inks. The discipline may also see an increase in the use of software and various recognition programs such as D-Scribe, FLASH ID, and Write-On 2.0.

The 2016 American Academy of Forensic Sciences (AAFS) Annual Scientific Meeting will also highlight many new techniques and developments in the scientific programs of each of its eleven sections. A key word search for the areas of interest for this particular study revealed a total of 41 submissions which have been scheduled as either a poster or an oral presentation: Latent print analysis (5 presentations); Fingerprint analysis (12 presentations); Friction ridge analysis (1 presentation); Firearms/Toolmarks (7 presentations); Tire print analysis (1 presentation); Friction tire testing (1 presentation); Bitemark analysis (10 presentations); and Questioned documents (4 presentations). Similarly as with the studies aforementioned studies, this key word search of the AAFS Annual Meeting presentations is not exhaustive. However, it does reveal the existence of research in the area and the recognition of the need to continually advance.

Jill Spriggs, President, CA Association of Crime Lab Directors

Necessity brings about research and development in certain areas. This will continue to be the case.

In forensic DNA, Next Generation Sequencing may provide significant advances in the information provided. In addition to phenotypic profiling for investigatory purposes, the ability to rapid sequence much more of the genome will give greater certainty in individualization. Drug detection in both blood and solid dose samples will benefit from improvements in tandem mass spectroscopy and time of flight instrumentation. The ability to rapidly and simultaneously analyze for large groups of drugs is important, including with the increased sensitivity and resolution of the new technologies needed for synthetics and high-potency analogues such as fentanyl derivatives. Digital forensics will benefit from improvements in biometrics and biometric databases. By augmenting current databases beyond fingerprints and palm-prints, these databases will be able to provide greater accuracy with identification, but also provide investigatory tools from video, photographs, etc. types of evidence. Current biometric growth areas include iris, face, tattoos, etc.

Randy A. Sandifer, Forensic Scientist, American Academy of Forensic Sciences

I believe that their will be more expansion on digital evidence relating to how it is collected and used in a court of law.

Matt Johnson, Orange County Sheriff's Department/OSAC Footwear/Tire Track Subcommittee

Imaging:

1. Hyperspectral imaging (HSI) is a technique that combines spectral and spatial information regarding an item of interest (Edelman et al. 2012). It is a non-destructive method that has extraordinary potential for the detection and recognition of footwear impressions deposited on a variety of substrates (Miskelly & Wagner 2005).

2. High dynamic range (HDR) photography is a method that can maximize shadows, mid-tones, and highlights to produce a single image with a demonstrably wider tonal range. Not exactly "new" or novel anymore though.

3. For shoeprint impressions with well-observed depth, three-dimensional scanning techniques are likely to become more commonplace. If validated, reasonably priced, and of sufficient resolution, 3D scanning could even replace or compliment traditional casting or lifting techniques (Gamage et al. 2013).

Question 5 – Standards of validity and reliability

What standards of validity and reliability should new forensic methods be required to meet before they are introduced in court?

Stephen E. Fienberg, Maurice Falk University Professor of Statistics and Social Science, Carnegie Mellon University

All forensic evidence introduced in court should be based on published methodology that meets scientific standards of quality and validity, and these methods need to be based on the analysis of detailed and representative data bases, that are publicly available and subject to review and possible challenge.

Steven Johnson, Board Chair - The International Association for Identification

Every forensic science discipline should be held to the same scientific rigor as any other applied science.

C. Michael Bowers, odontologist. Ventura Medical Examiner

A national council of scientists uninvolved and unemployed by forensic and law enforcement organizations. Professor Michael Saks (ASU) has advocated this for decades.

Joe Cecil, Senior Research Associate; Division of Research; Federal Judicial Center

The standards for admissibility of expert testimony are found in Rule 702 of the Federal Rules of Evidence, and require, among other things, that "the testimony is the product of reliable principles and methods." Therefore, the forensic sciences must demonstrate that the evidence they see to introduce is both derived from scientific principles using a methodology that allows a reliable (and valid) application to the issues presented by the case.

Frederick R. Bieber, Professor, Harvard Medical School

Methods should be shown to produce results which are accurate, reproducible, and valid. Field testing using blinded assays are needed before use in court.

Ahmed, PhD genetic engineering /DNA fingerprint

Next generation sequencing, mDNA , Y-Chr,X-Chr and DNA barcode

Mary Beth Hauptle, Forensic Odontologist, FCMEO

Any with known error rates of less than 5 %. The scientific means of identifying a decedent are Fingerprint, Forensic Odontology and DNA comparisons. I cannot remark on other specialties and their standards.

Melissa Connor, Director, Forensic Investigation Research Station

The Daubert standards are solid.

Tatiana Maria Blanco Alvarez, MA, Graduate student TTU

Be scientific based, have face validity, have construct validity, generalizable to different ethnic groups and cultures, have a bast scientific and theory base, count with validity and reliability statistical analysis to support them in different studies, and comply with ethic standards.

Femblix Meek Tom Jr, Student Citizencorps.gov AAFS.ORG Fvtc.edu Dna.gov Wvu.edu Bronx Community College

DNA databases contributes to reticence for change. These databases were developed to help investigate future crime and have been standardized on a core set of short tandem repeat (STR) or microsatellite loci (18,19). Because of the size of these databases [for example, there are >6 million reference profiles in the United States Combined DNA Index System (CODIS) database (20)], there is a substantial movement to maintain just the current core genetic marker repertoire. Additionally, because of the substantial resource outlay to validate molecular biology analytical systems, to equip a laboratory, and to educate and make proficient practitioners; as well as the efforts undertaken to gain admissibility in the courtroom (21), forensic scientists tend not to change sound methodologies quickly. One might predict, therefore, that there are not likely to be any dramatic changes in the molecular biology tools used in forensic science. Such a view cases ..

Heather Garvin, Assistant Prof of Anthropology/Applied Forensic Sciences, Mercyhurst University, Erie, PA

There need to be accuracy tests using the various equipment and methods of creating the models, as well as tests evaluating the accuracy of forensic methods (e.g., age estimation) when conducted on these 3D models, versus the actual specimens.

Pierre Margot, Emeritus Professor University Lausane

Their scopes and limitations should be well understood. Even poor techniques may be valid and reliable uncertain circumstances.

Mark Leney, Professor, UMass Medical School and Deputy Director, MassBiologics

I don't think that there should be an absolute standard of validity or reliability rather it must be possible to describe the limits of validity and express the reliability of the method in a manner that is accessible to the lay person and lawyer. My sense is that it is the coherency of such explication that should be gating factor, raising the interesting question of whether that should actually be tested in addition to performance characteristics of the method, that some standards of the clarity with which juries and attorneys understand a standard explanation of the method and its limitations be the gating factor rather than some arbitrary reliability standard. Some methods have lower reliability but might remain widely applicable - they should not be excluded, rather their limitations need to be understood AND explained.

Eric Warren, Ph.D., Special Agent/Forensic Scientist, Tennessee Bureau of Investigation

I think the standards have been set and are doing well. The problem has arisen from individuals that overstate their qualifications or overstate the confidence of their findings. This doesn't make the work they do any less valid, but it does give the forensic community a bad reputation. Instituting individual examiner certification will go a long way to help this issue.

Heather Edgar, Associate Professor, Curator, University of New Mexico

The standards set forth in the Daubert finding is acceptable.

Robert Gaensslen, Prof Emeritus, Univ of Illinois Chicago

Any method should be valid. It should always work the same way in competent hands. Reliability is similar. Methods should work across labs and platforms. I am also convinced we need to talk about standard deviations and error rates where they can be assessed. The jury needs to know the level of certainty attached to a result. This is easy with, say, drug identification, but not as easy with criminalistics evidence.

Dr. Sushil Kumar Sharma, Editor, EC Chemistry, UK

There should be one Basic Scientific Research program encompasses the physical, life, and cognitive sciences and is designed to increase knowledge underlying forensic science disciplines that are used in the Nation's criminal justice system. The Applied Scientific Research program is dedicated to the development of highly discriminating, accurate, reliable, cost-effective and rapid methods for identifying, analyzing and interpreting physical evidence. After approval it should be introduced to judicial system.

Edward Imwinkelried, Edward L. Barrett, Jr. Professor of Law Emeritus, University of California Davis

Synthesizing the DAUBERT line of authority, I believe that a proponent should have to demonstrate that by using the specific technique their expert intends to rely on, the expert can accurately draw the particular inference they propose testifying to.

Moses S Schanfield, Professor, Department of Forensic Science, George Washington University

All forensic technology should be meeting the same validation standards. The standards met for the introduction of DNA testing should be the same standards for other methods. If they cannot meet them, the weight of the evidence should be based on validity and reliability. In other words what is the probability of a correct answer.

Abigail Lehman, Criminalist III, Missouri State Highway Patrol

Repeatability, robustness

Rigo Vargas, QD Section Chief, MS Forensic Laboratory

Daubert and /or Rule 702 suffice.

Marianne Stam, Retired (in 2015) Criminalist Supervisor

Publication and peer review of related data; proven reproducibility of results etc...

Daryl Belock, VP, Innovation and R&D Collaboration, Thermo Fisher Scientific

Validation can often be built into workflows, but still requires human intervention. The spectral libraries we've developed are often validated via inter-agency / company comparison studies. We typically find that we discover new drug classes that require the creation of new spectras which then must be shared with the "fleet" of instruments out in the world. Today those methods are primarily manual in nature (downloading a pdf or software update file) and following an end-user defined process to implement the new information. In the future, we expect cloud-based methods to be created - likely be vendors given the lack of industry standards - to push / manage this spectra library information likely with administrative rights to customer super users.

James DiFrancesco, Forensic Biologist/ U.S. Army Criminal Investigation laboratory

All new methods need to undergo developmental validations as well as internal validations to show that they are reliable. They should be published in reputable journals and presented at in national forensic conferences to get community input.

Dr. L. Thomas Johnson, Professor (Retired) Marquete University

General acceptance by the applicable forensic discipline. Repeated studies that have demonstrated consistent results.

Chris House, Program Support Manager - National Forensic Laboratory Services

Complete methods should be published and peer reviewed and the method should be fully reproduced and validated in the laboratory it is being utilized. Full documentation of the lab's validation should be available for scrutiny if required in court.

Maciej J.Bogusz, MD, PhD, Prof.of Forensic Toxicology em.

The laboratory should be accredited according to ISO 17025, and the results produced should be accompanied by the whole documentation showing the adequate performance of the method applied. See: M.J.Bogusz ed.: "Quality Assurance in the Pathology Laboratory; Forensic, Technical, and Ethical Aspects". CRC Press, Boca Raton 2011.

Michael A Wagner, Indiana University Purdue University.

All methods currently applied to blood, urine and hair forensic toxicology with the exception of different limits of detection

Howard A. Harris, Professor Emeritus

Refereed publication and general scrutiny by appropriate scientific community

Dr. Geoffrey Stewart Morrison, Independent Forensic Consultant; Adjunct Associate Professor, Department of Linguistics, University of Alberta

All forensic methods, not just new ones, must be empirically tested under conditions reflecting those of the case under investigation using data sampled from the relevant population. In branches of forensic science such as forensic voice comparison where the relevant population and conditions are highly variable from case to case, testing of validity and reliability must be conducted on a case by case basis – there should be a Daubert / Rule 702 hearing for every case. See my response to Question 1 and the papers on testing referenced there, particularly: Morrison (2011), Morrison (2014), Enzinger et al (2015), Enzinger & Morrison (2015).

Glen Jackson, West Virginia University

Standard Daubert criteria are fine. However, I would argue that it's extremely helpful for Daubert hearings etc. to have a peer-reviewed monologue or review available that explicitly addresses how a particular technique meets each of the Daubert criteria.

Josep De Alcaraz-Fossoul, Researcher and Assistant Professor, University of Barcelona

Every new forensic method should at least meet the same criteria of acceptability as the ones currently being scrutinized. Many of the standards for forensic sciences are already included in ISO17025 or ISO9001 or other internationally accepted protocols. In the specific context of forensics, the U.S. Supreme Court suggested that the following factors be considered based on *Daubert* criteria:

- Has the method been tested in actual field conditions (and not just in a laboratory)?
- Has the method been subject to peer review and publication?
- What is the known or potential rate of error?
- Do standards exist for the control of the technique's operation?
- Has the method been generally accepted within the relevant scientific community?

In more detail, for high standards of reliability, the method should be tested-retested by administering the same test twice over a period of time to a group of individuals. The scores could then be correlated in order to evaluate the test for stability over time. Also, different versions of an assessment tool should be administered (versions must contain items that probe the same construct, skill, knowledge base, etc.) to the same group of individuals. The scores from the different versions could then be correlated in order to

evaluate the consistency of results across alternate versions. Finally, examiner's reliability should be tested because human observers will not necessarily interpret conclusions/results the same way.

For a method of high validity, it is necessary to ensure that the tool/method is actually measuring what it is intended to measure and not other parameters. Because an entire population cannot be covered, items need to be adequately sampled. These issues can be easily assessed by using a panel of "experts" familiar with the method and the measurements. In addition, the performance itself of the method has to be tested to be able to correlate test results with another criterion of interest. It is also important to assess how informative a
measure is to be able to provide significant data to help improve the matter under study.

Angi Christensen, Forensic Anthropologist, FBI Laboratory

I'm not clear here on what is meant by "standards." Methods should be tested in a way that validity and reliability for the technique are known. This is not the same as saying that there should be a validity or error rate "threshold" - it is more important that the science is sound, and that error rates are known/estimated and communicated properly.

David Brundage, Ballistics Laboratory Director, Aegis Sciences Corporation

Forensic laboratories currently apply scientific methodology to any new technique that may show promise to help in forensic examinations and/or evaluations of evidence.
This practice will be continued if it is to be introduced and accepted by the court system.

Dr. Rachel Bolton-King, Award Leader for Certificates of Professional Competence & Lecturer in Forensic Investigation, Staffordshire University

Ideally methods should be conducted as aligned to relevant ISO standards and be performed by organizations/laboratories/institutions accredited to meet those standards. However, by its nature, casework in some forensic disciplines, such as firearms and toolmarks identification, can involve a bespoke set of circumstances, factors and/or variables that mean that stringent standards and operating processes need to be altered and/or additional casework specific research is required to accurately test against and interpret the specific case scenario. Accredited and audited processes and procedures do not then allow flexibility to undertake such necessary research in these cases and therefore can inhibit research and development progress in a practitioner environment.

It is probable that in a vast field like firearms, that there is currently insufficient published research that takes into account the bespoke parameters of a particular case (including ammunition type and firearm model combination) and therefore casework specific research must be undertaken in addition to ensure correct interpretation. In such cases the time required for research to be published may not be sufficient to demonstrate extensive peer-review before a new technique is applied to casework. In such cases the evidence may be ruled inadmissible in court. An alternative could be that the evidence is admissible (if there is sufficient demonstration of repeatability and independent validity demonstrated to the court), but the potential limitation of the evidence explained to the jury/judge to ensure the appropriate weighting of the evidence is applied during deliberations. An example could include that there is limited research published on consistency and validity of using magazine marks (specifically made by manufacturer X) to make a reliable identification to firearm Z.

The issue of meeting standards for pattern-recognition based methods, however, does not assess the competence of the specific individual employing that method for forensic examination, analysis and/or interpretation. Neither does it asses the capability of the expert to explain their interpretation and underpinning science in a manner that the jury/layperson can understand to ensure that the weighting of the evidence is appropriate in a case. Being able to demonstrate to the court that the evidence analysis

provided is accurate is not just about the validity and reliability of the method but also the manner in which the method was carried out and the extent of testing in a specific set of case circumstances to demonstrate the accuracy, validity and significance of the interpretations made.

Carl C. Stacy - Director of Forensic Sciences/Chief Medical Examiner, University of Missouri Columbia, School of Medicine

This is a legal question. The Daubert standard is often used.

Mary K. Mainland, MD - Chief Medical Examiner, FL District 13

I am a forensic pathologist, not a laboratory worked. Forensic pathology is the practice of medicine. A forensic pathologist is a board-certified MD who determines cause and manner of death and documents diseases and injuries. The work product is the autopsy report, which corresponds tto the history and physical a physician performs on a living person. To be credible, a forensic pathologist should be certified by the American Board of Pathology in a minimum of Anatomic Pathology and Forensic Pathology. In court, the forensic pathologist is considered an expert witness, thus is qualified to state not only facts, but opinions. The testimony is no different that what would be provided by a physician caring for a living patient.

Joseph Prahlow - Professor of Pathology; Forensic Pathologist – Western Michigan University

For FP, new methods need to, first and foremost, make sense. Subsequent studies for validity and reliability will then depend on what the method is.

Bridget Lewis - President, International Association for Identification

Judges decide what to allow in court. Science pushes scientists to better understand, know, and explain parts of the universe around us. Courts push scientists to provide better explanations to the courts. Courts push courts to provide better decisions. The process of introducing a witness and allowing testimony is something the courts control and upon which the courts rule.

It is difficult to determine what needs to be specifically required before testimony about a specific method for a specific forensic comparative examination is introduced in court. However, since we are being asked, the validity and reliability of forensic comparative science can be generalized across similar disciplines. The totality of the similar comparative science disciplines and their histories can be brought into court. Analyses of the first impression/image/object, analyses of the second, comparisons of the two, and evaluations of the analyses and comparisons is a process of seeing, thinking, then knowing and believing about details of the features of the source object. It is a very good and simple description and process we can use to study and document our examinations. Comparative science can generalize across objects and across impressions or images. If some specific comparative science disciplines are accepted in court, the line of demarcation that disallows testimony in another similar discipline seems to be a gray blur.

Cognitive science is trying to understand how we see, think, know and believe. Philosophy is trying to explain how we do this. Statisticians are applying values to details in impressions and images. Bring cognitive scientists, philosophers of science, and statisticians into forensic comparative science for collaboration and research and understandings and sharing as we strive to provide better validation and reliability to the court.

Experts should meet standards before they are allowed to testify in court. The court must decide whether any person within a wide variety of proposed experts should be allowed to testify. The courts should determine whether the proposed expert is capable of answering the relevant and appropriate questions the triers of fact are pursuing in court. How the triers of fact should go about determining this is a great

challenge. Possibly, more pre-trial challenges of expert testimony should occur.

The newly formed National Commission on Forensic Science meets several times per year. During a recently live-streamed meeting on December 8, 2015, the Training on Science and Law Subcommittee presented a report for approval of the commission. Subcommittee Co-Chair, Judge Barbara Hervey presented their document entitled: "Directive Recommendation on National Forensic Science Curriculum," and stressed the importance of educating judges and lawyers on standards and aspects of forensics science and its capabilities. This training would be extremely valuable as lawyers regularly argue the positive or negative side of forensic evidence and try to have certain examinations/evidence deemed admissible or inadmissible. The judges are the gatekeepers and determine what evidence is allowed into the courtroom and they may be making uninformed decisions due to lack of understanding. Proper training of judges may lead to closer scrutiny of expert witnesses and their authorization to opine during the proceeding. However, many judges will not receive this training. They cannot receive training in all the disciplines in which experts might testify. However, judges still need to scrutinize the expertise of the proposed witness as related to comparison science. See:

1. http://www.justice.gov/ncfs/training-science-and-law
2. http://www.justice.gov/ncfs/file/641696/download
3. http://www.justice.gov/ncfs/file/794611/download

The courts have established admissibility guidelines that are meant to answer this question. Reliability of the comparative science disciplines is established in the same way reliability is established in any other scientific discipline. In the end it comes down to accuracy and repeatability. The techniques and methods used in the forensic comparative sciences should be held to the same admissibility benchmarks as other proffered methods and techniques. Consideration should be given to the fact that the comparative sciences are unlike some of the other forensic disciplines in that the results are not instrumentally driven. Because of this, it is currently not possible to generate traditional "error rates" as a point of inquiry into reliability as suggested by the Daubert court and Federal Rules of Evidence. Humans and their vision system are the primary instruments in the comparative sciences and as such need to be routinely tested and their results verified, just like other instrumentation.

Sue Pearring - Senior Criminalist, Los Angeles County Dept of Medical Examiner-Coroner

This does not apply to all methods and disciplines, but in general these parameters should be evaluated and shared: accuracy, precision, stability, robustness.

Paul L Morrow - Forensic pathologist, Auckland, NZ, formerly Chief Medical Examiner, Vermont

Acceptance and experience in diagnostic medical practice, specifically related to postmortem techniques in the case of forensic pathology

Eoghan Casey, Multiple titles and affiliations related to digital forensics and cyber investigation

Digital evidence requires a comprehensive approach to establishing confidence, as outlined in the SWGDE document "Establishing Confidence in Digital Forensic Results by Error Mitigation Analysis"

This question is an important question that digital forensic researchers and practitioners have been working together for many years to addressed. The most recent effort to address this question is the SWGDE document "Establishing Confidence in Digital Forensic Results by Error Mitigation Analysis" (Version: 1.5, February 05, 2015).

Deion P. Christophe, Firearm Examiner III/Section Supervisor IFL/NMS Labs

As with any "new" field of expertise it should be validated for accuracy and practice. There are going to be many barriers that this application will face. Many of which will come from a body of members who may be less than acceptable to change. The current state of optical topography is undeveloped and there remains to be a great deal of practical application research needed. The largest requirement that will need to be met will be in relation to developing an appropriate objective component that supports the existing conclusions established by this discipline. Determining how much similarity is needed; are there a suitable amount of consecutive matching striae needed, and most of all; are there minimum amounts of criteria needed to confirm or render an identification? These will all be some of the most important aspects of future research and standardization.

Professor Sue Black and Professor Niamh NicDaeid, Professors at CAHID, University of Dundee, UK

Admissibility is a matter for the judiciary and the court to assess and decide. The admissibility threshold will vary depending on the nature of the evidence type but should require appropriate scientific studies to have been undertaken and been made available for scientific scrutiny usually through peer review, such that there is general acceptance of the scientific principles being used and the context in which they are being deployed within the criminal justice process. The necessity to have this robust scientific underpinning has been emphasised recently by the Lord Chief Justice of England and Wales in his 2014 Kalisher lecture to the Criminal Bar association where he stated that:
'the credibility of the criminal justice system depends on the quality of the science underpinning the forensic evidence, in order to preserve confidence in the experts and the evidence they present'.

It is also critically important that the agreed robustness of the science underpinning a particular evidence type is conveyed to the legal practitioners and the jury. In recent developments within the UK a project has been agreed between the Royal Society, the Royal Society of Edinburgh and the Office of the Lord Chief Justice to produce a series of 'judicial' primers which will communicate the basic science behind and underpinning forensic evidence, thus providing an undisputed baseline of understanding for all parties. This project will be led by Profs Black and Nic Daeid.

Xhemajl Ademaj, Fellow American Academy of Forensic Science

It was good that the methods to be valid and allowed by the quality office or quality manager. Or accredited with ISSO 17025

Michael T. Beddow, Forensic Scientist IV, Phoenix Police Department Crime Laboratory

Protocols currently in place to validate new methods and techniques have proven more than sufficient to meet all of the necessary standards and needs set forth by the various court systems.

Andy Smith, Chair - Firearm/Toolmark Subcommittee NIST OSAC

In anticipation of the role that technology will play in the near future for Firearm and Toolmark Examination, the Firearms/Toolmarks subcommittee of the Organization of Scientific Area Committees (OSAC) is in the process of writing and publishing validation standards for the implementation of new technology in the firearms and toolmark laboratory.

Tim Schellberg, President, Gordon Thomas Honeywell Governmental Affairs

We are comfortable that the forensic DNA community, through groups like the congressionally mandated Scientific Working Group on DNA Analysis Methods (SWGDAM), and through the collaborative efforts of Organization of Scientific Area Committees (OSAC), will be guided to utilize appropriate scientific validation methods in order to adequately establish new technologies for introduction in court.

Clifford Spiegelman, Distinguished Professor Texas A&M U

Same as mainstream science. For too long judges have accepted and keep accepting it because the last judge accepted it. While the underlying 'science' looks promising, we are 5-15 years from having firearm/toolmarks on solid ground. Till then testimony should be restricted to 'this gun cannot be ruled out as the murder weapon etc.' rather that this was the murder weapon to a practical degree of certainty or some other ridiculous statement. Firearm/toolmark testimony is closer to religious statements than scientifically supportable statements

Brandon Giroux, President, Association of Firearm and Tool Mark Examiners (AFTE)

Validation is the process by which the scientific community acquires the necessary information to (a) assess the ability of a procedure to obtain reliable results, (b) determine the conditions under which such results can be obtained, and (c) define the limitations of the procedure. New forensic methods which have not been scientifically validated or has been validated but not adopted for use in the field of forensic science should undergo a developmental validation process before they are introduced in court.

Developmental Validation should include:

1. Literature references: Review of publications, academic materials, etc. involving the technique or procedure being validated.
2. Simulated casework samples which are representative of the samples routinely analyzed using the technique or procedure.
3. Accuracy/Precision Studies: The results must demonstrate that the method is capable of delivering the level of accuracy and precision required for the particular application of the method. The accuracy (proximity to accepted values) and precision (acceptable level of variability) must be demonstrated to be acceptable for forensic casework.
4. Reproducibility: The test must be reproducible by another individual using the original test documentation.
5. Specificity: Where applicable, the method should be demonstrated to yield results which are specific to the items analyzed.
6. Sensitivity Studies: The sensitivity of the method should be demonstrated when relevant to the validation process.

A new technique or method requires more thought and subsequent testing to properly satisfy validity and reliability issues. By way of an example, recent and rapid developments have taken place in the field or digital imaging of fired bullets and cartridge cases. A comparison of images of these items taken through a traditional optical microscope with digital images of the same objects generated with this ‘new’ technology are visually striking. [See Figure 1 and Figure 2] So much more detail becomes visible in the toolmarks on these ballistic items. Moreover, previous problems with specular reflections (“hot spots”) with traditional illumination of shiny surfaces are totally obviated with these digital imaging systems. Conversely, areas that are dark under normal illumination are easily seen as gray scale images with these same digital systems. The two attached figures show a cartridge case comparison and a bullet comparison with a traditional optical comparison microscope and one of the current digital scanning systems. One might argue that the substantially superior nature of the images generated by the digital scanning system are self-evident or self-authenticating, and that a court should easily be able to see the improvement offered by such a digital scanning system. But lacking expertise in firearms and toolmark examination on the part of a judge, an alternate and more appropriate procedure for validity and reliability, suitable for peer review using this example of a ‘new’ technique, would be as follows:

1. Select a polygonally-rifled firearm such as a Glock or H/K P2000, and ensure (through a subsequent bore cast) that the bore is unique by minimally lapping it with fine grain SiC in a liquid base. [Note: this type of barrel is chosen because it is often very difficult to impossible to match test-fired bullets under the conventional optical comparison microscope]
The lapping process will produce micro-imperfections in the bore in a random manner thereby rendering the barrel unique.
2. Prepare indexed, test-fired bullets after multiple shots (5-10 shots) to assure that the "settling in" process is complete.
3. Verify that these bullets cannot be definitively matched using a state-of-the-art optical comparison microscope.
4. Prepare photomicrographs showing the best (if any) areas of marginal agreement on these test-fired bullets.
5. Scan and re-examine all test-fired bullets using one of the state-of-the-art digital imaging systems such as Evofinder, IBIS Trax-HD3D, or LUCIA Bal-Scan.
6. Record the best matches with digital imaging system.
7. Prepare side-by-side comparisons between the results for the same areas with the optical comparison microscope and the digital imaging system.
8. Repeat the experiment with other barrels producing difficult to impossible to match test-fired bullets.

Validity and reliability in this example are established with the repeated success of the digital imaging system with its demonstrated ability to make visible unique striae patterns not discernible with the traditional optical comparison microscope. Subsequent peer review by the relevant scientific community would also represent an important consideration if, and when, critics raise a legal challenge to the use of this new technology.

American Academy of Forensic Sciences (AAFS) Board of Directors

Due to the diversity and breadth of the field and continuing advancements, it may be difficult to identify specific standards for testing the validity and reliability of new forensic methods. It may be in the best interest of the forensic community and those served by the community to devise the standards as the research and methods improve. However, standards to keep in mind would be those already identified by the legal community in opinions such as Frye and Daubert and the Federal Rules of Evidence (FRE), particularly FRE 702.

Jill Spriggs, President, CA Association of Crime Lab Directors

New methods are validated prior to their use in actual casework. Generally, validation includes the following as applicable: a demonstration of the accuracy of the method (how close does the method get you to the true value), limits of detection (at what point is the amount of sample so small that the method doesn't detect it), precision (how repeatable are the results with this method), specificity (does the method detect only what it is intended to measure), and reproducibility (do multiple analysts get the same result from the same sample). Robustness (what happens when some parameters of the analysis are changed) and ruggedness (whether the technique will work in a variety of laboratories) may also be included in method validations.

Randy A. Sandifer, Forensic Scientist, American Academy of Forensic Sciences

The validity and reliability of forensic evidence that include new methods should pass Frye's Standard. This standard is the baseline for all forensic evidence that is used in the court of law.

Matt Johnson

Generally validity is synonymous with accuracy and reliability is akin to precision. As such, accuracy refers to the closeness of a measured value to a standard or known value. Conversely, precision is a description of the consistency of the measured values.

Standards of validity (accuracy):

- Suitability – the method should test what it is expected to test; in other words, it should fit the purpose for which it was intended.
    - In examination, this would probably mean that the expert should not base their interpretation process on improper data. Relates to training, testing, proficiency, etc.
    - If a numerical method, it must be fully vetted. For example, if a circle has more degrees of freedom than a line (e.g., you can rotate a circle and it still looks like the same circle, but if you rotate a line, it has a different orientation) does your numerical metric capture this? Do you want your numerical metric to capture this?
    - If using pixel-based RAC images, is your numerical metric sensitive to pixel differences? Is this acceptable? Should you treat your RACs as vectors instead of pixels? How does this impact the results?
- Availability of independent verification – there is independent evidence to show that the method works or is reporting as close to the true value as possible.
    - This may take into account the variability among different examiners.
- Justifiable variability – the range in variation/difference should be substantiated/expected and demonstrated. When variation falls within the expected or accepted range, it is considered reasonable. Variation outside of this range must be approached with caution since it is falls outside the common confidence interval.
    - What range in loss RAC can be expected based on transfer mechanisms?
    - What range in loss of RAC complexity and quality can be expected based on transfer mechanisms?
    - How does size impact RAC loss in transfer mechanism?
    - How does RAC shape impact RAC loss in transfer mechanism?
    - How does substrate impact RAC loss?
    - How does media impact RAC loss?

Standards of reliability (precision):

- Identified sources of error – in addition to establishing error rates, what are the sources of error? Factors contributing to differences in reported values should be identified, and if possible, quantified in order to provide a frame of reference when assessing the reliability of the method.
- Measures to mitigate sources of error – after identification, there should be steps to increase consistency in measurement. These steps should be effective in ensuring the precision of the reported values.
- Recognition of constraints – the limitations and range of a particular method should be determined. This can be obtained through control tests or via extraction from routine applications.

Additional Expertise

Question 6 – Other scientific and technology disciplines

Are there scientific and technology disciplines other than the traditional forensic science disciplines that could usefully contribute to and/or enhance the scientific, technical and/or societal aspects of forensic science? What mechanisms could be employed to encourage further collaboration between these disciplines and the forensic science community?

Stephen E. Fienberg, Maurice Falk University Professor of Statistics and Social Science, Carnegie Mellon University

The key discipline required to advance the evaluation of forensic evidence is statistics. But this field needs to be integrated with the traditional forensic evidence disciplines for effective assessment of the science underlying forensic evidence.

Steven Johnson, Board Chair - The International Association for Identification

Touch DNA appears to be making some other forensic disciplines somewhat obsolete. That said, there is always room for these disciplines as they apply to criminal investigation and ultimate identification (or exoneration) of persons of interest. It is my experience that the forensic community writ large is open to new technologies, methodologies and research in the interest of improving the forensic sciences and finding the truth.

C. Michael Bowers, odontologist. Ventura Medical Examiner

The NIJ praises itself for funding forensic science. It is a paltry figure in comparison to mains stream academic and commercial research. Research is driven by funding. Universities follow the money. Considering the end user of forensics is the US criminal justice system with its enormous economic infrastructure, this imbalance is absurd.

Joe Cecil, Senior Research Associate; Division of Research; Federal Judicial Center

Mainstream scientists should start to examine issues considered by forensic scientists, and bring the forensic scientists to the community of mainstream scientific values and practice.

Frederick R. Bieber, Professor, Harvard Medical School

Audio, video and other digital/computer imaging, voice recognition. Understanding of how jury members interpret statistical data will be crucial as new forensic methods are introduced.

Ahmed, PhD genetic engineering /DNA fingerprint

All Forensic Must Have Reliability And Honest.

Mary Beth Hauptle, Forensic Odontologist, FCMEO

Facial recognition software.

Melissa Connor, Director, Forensic Investigation Research Station

Statistics is the first one that comes to mind. The practitioners, however, need to embrace other disciplines.

Tatiana Maria Blanco Alvarez, MA, Graduate student TTU

Disciplines like entomology, archaeology, engineering, odontology, accounting, nursing, that can have a forensic application. It's important to create protocols that include different disciplines in order to complete them, as well as publishing interdisciplinary studies.

Femblix Meek Tom Jr, Student Citizencorps.gov AAFS.ORG Fvtc.edu Wvu.edu Bronx Community College

Extracting evidence from forensic DNA analyses: future molecular biology directions

Heather Garvin, Assistant Prof of Anthropology/Applied Forensic Sciences, Mercyhurst University, Erie, PA

Yes - engineers are used to using 3D models and testing them. We could incorporate their expertise, as well as computer scientists to create programs to perform analyses more efficiently. There is always the need for stronger statisticians in the field to help create appropriate analyses. Most of the time these disciplines pay more than our own - maybe more grants supporting interdisciplinary collaboration would help.

Pierre Margot, Emeritus Professor University Lausane

Crime analysis and forensic intelligence are keys to understand the strength and scope of the contribution of forensic science. Social sciences may contribute in establishing the effectiveness of processes.

Mark Leney, Professor, UMass Medical School and Deputy Director, MassBiologics

As a forensic investigator who has made the transition to FDA regulated manufacturing I think there are many parallels between the highly regulated field of food and drug sciences and the less highly regulated world of forensic sciences. Although forensic sciences don't impact the safety of citizens every day in the way that safety of food and drugs do, there are substantial similarities. The major difference as I see them is that the food and drug law requires quality standards and independent quality units on a statutory basis, licensing is subject to statute and regulation and inspections by regulators are frequent and penetrating. Of these, I think the development of a unit more analogous in implementation to the way that the Quality Unit called for under 21 CFR 211.22 is implemented in the pharmaceutical industry would have the greatest impact - there are many aspects but control and review of written procedures, documentation and investigation of departures from written procedures, independent review of results, control of validation, training, record keeping and formal system of corrective and preventative action are key elements of the pharmaceutical quality system that would transplant well. Frequent inspection would also help in my opinion including inspection of training and validation records as well as casework, procedures and deviations from procedures. I am on the fence if state or federal licensing should be implemented but clearly the current accreditation is patchy and the benefit it brings questionable. Accreditation is not mandated so it may be that labs that are already at high performance levels seek accreditation. Accreditation might thus be a self-identification of higher standards but do nothing in itself to raise them.

Maria Susana Ciruzzi, PhD Criminal Law and Bioethics. AAFS Jurisprudence Section. Law School University of Buenos Aires

As a lawyer and bioethicist working at a pediatric hospital, we train health professionals in evidence collecting in a way to preserve it, help our patients when they are victims of a crime and facilitate courts' work. Clinical charter has been a very important source of evidence, especially to avoid victimization of the child: health professionals write down, in the child's own words, what he can tell us about the crime, the place and the perpetrator. Then, we hand this to court, in order they can have a statement of the child from somebody he trust, and if it's necessary, we offer our testimony at court. Developing this kind of work is worth it.

Eric Warren, Ph.D., Special Agent/Forensic Scientist, Tennessee Bureau of Investigation

The metallurgy and mechanical engineering disciplines could help FA/TM Examiners better understand the forces that act on the metals involved in ammunition and firearms when a firearm is discharged. The confocal microscopy and surface tomography disciplines would greatly help us advance our 3D surface examination techniques and technologies. Holding more free webinars and seminars (as NIST and others already do), would encourage collaboration and introduce the practitioners in varied fields to one another.

Heather Edgar, Associate Professor, Curator, University of New Mexico

I work primarily in bioarchaeology and human biology, but my research has clear forensic applications, which I have published. There are many other researchers who could be working across disciplines. However, it can be difficult to get funding across disciplines supported by multiple federal agencies, as each may be see the research as pertinent to another. The NSF's dear colleague letter regarding forensic science may indicate some easing of this tension.

Robert Gaensslen, Prof Emeritus, Univ of Illinois Chicago

Yes. A good example is biometrics and fingerprint comparisons. Maybe retinal scans will be next. In pattern areas, pattern comparison software is key -- and is devised mostly by engineers. I have also see promising work by fluid mechanics engineers in blood spatter. On the social science side, papers on unintentional bias are important.

The key to collaboration is probably money. NIJ needs a lot more money if you want this to happen. And truthfully, some law enforcement types are not so much in favor of these types of collaboration. There is a feeling (not unjustified) that the defense bar is "out to get' the forensic scientist under the banner of honest reporting. Does a defense lawyer want blind PT because he wants to insure quality, or because he would like to 'catch' someone in an error?

Dr. Sushil Kumar Sharma, Editor, EC Chemistry, UK

Strengthening forensic science is a complicated challenge that will require considerably more work and a sustained commitment on the part of the Federal Government as well as the broader forensic science community. This document will be updated periodically to reflect the Administration’s continued progress in this area. The regularities and funding agencies should come with common program “Academia-Industry-Regulatiries Interaction” to get more reliable and authentic outcome in research.

Moses S Schanfield, Professor, Department of Forensic Science, The George Washington University

Forensic science is applied science. As scientific technology advances, there will be new technology. DNA was not on the horizon when I started working in forensic science. I have no idea what will be there when I leave.

Marianne Stam, Retired (in 2015) Criminalist Supervisor

GIS practitioners; Academic Liaisons who are skilled in statistics; Isotope Ratio Mass Spectrometry practitioners.

Joint conferences; joint training exercises/hands-on workshops involving vendors, academics with the above skill sets, and forensic scientists. Also the continued support of technical working groups such as the current OSAC committees/subcommittees that include statisticians and scientists who are not forensic scientists but are in related disciplines.

Michael Kusluski, Forensic Scientist, Michigan State Police

In the 1970s/1980s, clinical laboratories faced the same problems as forensic labs. In many ways, this field is the closest adjunct to forensic science. Many of the innovations (e.g., automation) should be adopted by forensics labs.

Dr. L. Thomas Johnson, Professor (Retired) Marquete University

Programmers and software developers who could develop an automated system to scan, measure and store measurements independent of the researcher.

Chris House, Program Support Manager - National Forensic Laboratory Services

In toxicology, cross discipline collaboration with pure chemists and drug synthesis should be available either for consult or collaboration in forensic toxicology. Forensic toxicologists are very good at testing for and interpretation of what is known but more and more unknown compounds are being detected and having a synthetic chemist who can develop and provide chemical standards for testing is becoming more critical. In all disciplines, there is a paucity of the understanding of statistics. Collaboration with experts in statistics and the proper interpretation of validations, analyses, and research in each respective field needs improvement.

Maciej J.Bogusz, MD, PhD, Prof.of Forensic Toxicology em.

As concerns forensic toxicology, close collaboration with clinical chemistry and laboratory medicine is a must. These disciplines provide extremely important information on toxicokinetics and behavior of toxicologically relevant compounds in various physiological and pathological conditions. Molecular pathology and pharmacogenomics may greatly improve the ability of the proper interpretation of forensic results. Additionally, clinical chemists in Europe elaborated coordinated and harmonized standards of professional requirements for professionals. These standards were formulated in EC-4 Register. Similar register would be very useful for forensic experts as well. An establishing of some coordinating committee for forensic experts, clinical chemist, and molecular pathologists would be useful.

Michael A wagner, Indiana University Purdue University

Pharmacogenetics as it applies to drug metabolism, individual toxicology profiles and drug/drug interactions.

Howard A. Harris, Professor Emeritus

Much of the currently rounded research in forensic topics is being done by good scientists who know too little about forensic science.

Dr. Geoffrey Stewart Morrison, Independent Forensic Consultant; Adjunct Associate Professor, Department of Linguistics, University of Alberta

At present, the major problem is not a need for contributions from scientific and technology disciplines outside of forensic science, rather it is a need for forensic scientists to adopt a new paradigm based on advancement which have already been made in the field of forensic inference and statistics. Within many branches of forensic science (including forensic voice comparison) there is substantial resistance to change (Curran, 2013) – this is in the nature of a paradigm shift (Kuhn, 1962). Courts and bodies with powers to regulate forensic science must insist on the adoption of a new paradigm which includes logically correct reasoning and empirical demonstration of validity and reliability under casework conditions.

See references.

Glen Jackson, West Virginia University

We need more statistics in forensic science disciplines. We need more funding and more research active students and faculty (i.e. PhD programs) to help build a more rigorous body of knowledge. If the government increased funding for forensic science research, the talent--and benefits--would follow.

Josep De Alcaraz-Fossoul, Researcher and Assistant Professor, University of Barcelona

In the era of high degree of specialization of global crime (i.e. terrorism, sexual exploitation, human and weapon trafficking and drug smuggling, just to mention a few) forensic sciences have been overtaken by the fast diversification and extension of these interrelated illegal networks of delinquency. I believe that one of the most effective ways to tackle this emerging worldwide problem is by encouraging multidisciplinary forensic sciences, or in other words, the development of forensic intelligence.

In order to fight terrorism and human trafficking forensic intelligence can be easily applied to, for example, questioned documents, drug analysis, fingerprinting and DNA profiling. The interrelation of these disciplines will undoubtedly proof useful towards our societies' safety and preservation of freedom. The good news is that the scientific basis and technical capabilities already exist in most modern countries which make international collaborations, including those between Governments, a feasible line of work.

Once the goal is set, it is the duty of forensic experts to explain to international organizations and national governments the great potential of FSD in fighting crime beyond the daily casework at a regional scale. As with other scientific disciplines, funding will be required to bring together national-international collaborations, multidisciplinary studies, data share, etc. Two of the mechanisms that could be used to encourage global FSD are: 1) Promoting multidisciplinary scientific conferences at a governmental level, and 2) creating international/national committees to evaluate the current status of information exchange.

David Brundage, Ballistics Laboratory Director, Aegis Sciences Corporation

Contributions to forensic science continually come from both traditional and non-traditional fields of science and technology disciplines. Many current practices and/or valid techniques have come from such sources in the past, and will continue to do so, especially as forensic science expands and research in new areas developed.

Dr. Rachel Bolton-King, Award Leader for Certificates of Professional Competence & Lecturer in Forensic Investigation, Staffordshire University

With respect to firearm identification and other pattern recognition based disciplines there is much scope for the fields of computer science and data analysis to further develop integrated pattern recognition based algorithms/software for forensic evidence comparison and interpretation, which can be exchanged between databases.

Computational software also needs to be developed to create an automated intelligence cycle to more effectively combat crime by using forensic analysis of evidence in a proactive way rather than reactive, continuously analyzing data and feeding intelligence back into policing. For example, collecting, integrating and frequently interrogating forensic analysis/intelligence with law enforcement programs to predict crime, link crime series and allocate law enforcement resources effectively in a district/region to reduce crime occurrence.

With respect to shooting incident reconstruction, trajectory determination and forming trajectory simulations this could be within areas of computer modelling and games design.

All research requires significant financial input from funding sources (companies, government/private funding streams etc.) to buy in the time and expertise for individuals to contribute and collaborate. Both academics and practitioners/ professionals in the forensic science disciplines appreciate that research is

required to advance this vital discipline to support criminal justice system. However, there is still currently a miss-match between each professional's priorities and understanding of roles leading to a lack of effective communication and engagement between practitioners and academia to expand research in forensic science disciplines, especially those not associated with DNA analysis. Most practitioners' priority is to undertake casework so typically do not have the time to conduct wider non-casework specific research themselves and other organizations/institutions operate as businesses and therefore can no longer be sustainable by conducting pro-bono research.

Establishing joint conferences, networking events and committees with academic and practitioner members across interdisciplinary fields would support wider collaboration, along with training events to enable practitioners and subject experts to be made aware of other practice and seek out how other disciplines could benefit the forensic fields.

With respect to all forensic disciplines in my opinion it is not just the scientific method that requires improvement to ensure the correct verdicts are drawn in the courtroom. There is a much broader issue that needs to be addressed as indicated in my recent paper on preventing miscarriages of justice (attached), which can be applied to a range of forensic disciplines outside firearm identification. Such improvements should include:

- Increasing the communication between expert witnesses and legal professionals prior to giving evidence (e.g. questioning of qualifications and practice undertaken by the expert, seeing demonstrated evidenced of testing/research to support interpretations made related to casework);
- Increased training for expert witnesses to educate non-experts (especially the jury) during court proceedings to ensure they understand the scientific evidence presented;
- Preventing non-experts delivering training to other non-experts in subject matters outside their field of expertise (i.e. legal professionals not training/educating others in the theories underpinning a specific forensic discipline unless they have been a qualified trained practitioner previously).

Carl C. Stacy - Director of Forensic Sciences/Chief Medical Examiner, University of Missouri Columbia, School of Medicine

As time goes on forensic science involves all of the sciences including social sciences. We can continually develop new techniques (such as neovascularization gene studies in dating injuries) but it will need to be funded.

Mary K. Mainland, MD - Chief Medical Examiner, FL District 13

Forensic pathologists provide expert testimony related to the cause and manner of death. They collect critical evidence in criminal cases(eg., bullets). Though medicolegal investigation of certain types of death is MANDATED nationwide, the US has a severe shortage of forensic pathologists. Many medicolegal autopsies are being perfomed by unqualified physicians. It is certain that cause and manner of death are determined incorrectly and necessary documentation and evidence collection are not being done, in huge numbers of cases. The discipline of forensic pathology needs to be better funded and supported at the national, state and local levels.

Joseph Prahlow - Professor of Pathology; Forensic Pathologist – Western Michigan University

Statistics. Recognize that "science" is not limited to the "scientific method"

Bridget Lewis - President, International Association for Identification

Yes! Any science can be needed in court. Then, it can be considered a forensic science. It is difficult to label a forensic science as traditional or non-traditional. Some of these traditional or non-traditional forensic science disciplines include, but are not limited to:

1. photo/video comparisons involving data of people and faces, irises, hands, skin, or vehicles, clothing,

nature scenes, or objects of any types.
2. fractured, torn, or separated items, such as tapes, glass, plastics, papers, wood, natural objects, etc. Any naturally, humanly, or machine-made object can be physically examined and compared to another object to judge whether common origin can be determined.
3. lip, ear, or skin impressions.
4. foot morphology or hand morphology in impressions or images.
5. fabric impressions, such as from gloves or socks.
6. rubber glove impressions.
7. patterns found on animals. Note: OSAC has a Wildlife Forensics Subcommittee who will focus on standards and guidelines related to taxonomic identification, individualization, and geographic origin of non-human biological evidence based on morphological and genetic analyses. See: http://www.nist.gov/forensics/osac/sub-wildlife.cfm .
8. see www.forensic.org for a wide variety of disciplines.
9. anything that can be compared for the needs of the courts.
10. and bite mark evidence.

Emphasis must be added that the measurements of details in the above categories must be sufficient. Bruised skin in bite mark impressions might not depict sufficient quality and quantity of details to reach a significant conclusion. Bruised skin is an example, but any substrate may not record sufficient details of the features of the object that made the impression or image. Sufficient understanding and measurement of the details in any impression/image/object is needed to reach a significant conclusion.

Sue Pearring - Senior Criminalist, Los Angeles County Dept of Medical Examiner-Coroner

A greater understanding and awareness of cognitive bias in the context of forensic science analysis is needed. Real examples of where cognitive bias played an adverse role in the progression of a case are powerful. Real examples of how laboratories have trained their employees, implemented workflow improvements and common issues that arise surrounding these strategies would also greatly benefit the community.

Paul L Morrow - Forensic pathologist, Auckland, NZ, formerly Chief Medical Examiner, Vermont

Other medical specialties, specifically in the case of forensic pathology

Eoghan Casey, Multiple titles and affiliations related to digital forensics and cyber investigation

Behavioral Science, which can be helpful for interpreting traces and patterns in digital evidence. Although digital and multimedia evidence has been accepted as a discipline of forensic science, it continues to evolve as new technology is developed and put to new uses. It would be mutually beneficial to increase collaboration between digital forensic practitioners and those in other forensic disciplines. Methods from traditional forensic science disciplines can be translated into the digital realm. Digital and multimedia evidence can contain information that reinforces traditional forensic science disciplines. Workshops that encourage knowledge sharing between digital forensic practitioners and those in other forensic disciplines would help foster this cross-pollination.

Deion P. Christophe, Firearm Examiner III/Section Supervisor IFL/NMS Labs

I believe the largest encouragement to be employed should be the relationship between practitioners, academics and federal government agencies. It seems apparent that when grants and funding is available for such research along these lines many state and local agencies cannot get the necessary financial support needed to assist in the expansion of research that would assist in change. Yet, there seems to be multiple collaborative efforts in the federal sector that get funded and supported. While it is important to be

structure in the approach to advance any science, there should also be an initiative to get some of the state and local agencies involved so that the furthering of the knowledge and research is not so one-sided, especially when the methods and procedures are presented to the greater body of practitioners.

Professor Sue Black and Professor Niamh NicDaeid, Professors at CAHID, University of Dundee, UK

The recent report released by the Chief scientific advisor for the government office of science in the UK addresses in part this very question. It draws parallels across the forensic science ecosystem and approaches used to other areas and ecosystems where synergies either already exist or could be defined. The report is available here https://www.gov.uk/government/publications/forensic-science-and-beyond

Xhemajl Ademaj, Fellow American Academy of Forensic Science

Psychology as a Forenzik discipline has a good possibility identification in connection of offence preporeters with other acters , assistance on criminal offenses.

Then statements of defenders sand witnesses are much more stable after an analysis that is done by forensic psychology expert.

On Forensic expertise pathologist and anthropologist could be engage directly in Forensic matter with a commitment not just static in the laboratory but also in their approach to the scene.

In countries where there are wars or having membership in a conflict during the past where victims are identified after a period during structural decomposition of the body then the anthropologist commitment is necessary.

Michael T. Beddow, Forensic Scientist IV, Phoenix Police Department Crime Laboratory

Many other scientific disciplines can and do collaborate with forensic science. With respect to Forensic Firearm and Toolmark Examination, scientific and technology disciplines that could provide the most benefit would be fields such as metallurgy, mechanical engineering and computer engineering. To allow for better collaboration between “traditional forensic science disciplines” and other scientific disciplines mechanisms need to be developed that will allow for these fields to work together rather than independently. It has been a far too frequent occurrence where members of other scientific communities, either in industry or academia, feel that they should be responsible for research and “the science behind forensic science” without input from practicing forensic scientists. What must be remembered in order for inter-disciplinary collaboration to be made possible is that the label “forensic scientist” is only given due to the environment in which we as forensic scientists perform our work. At the core we are all educated scientists (chemists, biologists, physicists, etc.). As with any scientific discipline it would not be prudent to begin to research and/or scrutinize a specific topic without first having an understanding of the subject matter at hand.

Andy Smith, Chair - Firearm/Toolmark Subcommittee NIST OSAC

The Organization of Scientific Area Committees, established by the National Institute of Standards and Technology (NIST) has as a primary goal to answer this very question. The majority of forensic science disciplines have now been brought together within one entity with a purpose of establishing scientifically sound standards of practice within each discipline. The ability to share knowledge and research and to collaborate between like disciplines is now a greater possibility which will only serve to enhance the technical and societal impacts of forensic science.

Specifically within the discipline of firearms and toolmarks comparison, our profession has begun collaboration with computer scientists utilizing machine learning algorithms. Machine learning is a

subdiscipline of computer science that utilizes probability and statistics to develop algorithms for pattern recognition. Since the comparison of toolmarks is the comparison of patterns, the collaboration between firearms and toolmark examiners and computer scientists is a collaboration that has started to produce interesting research papers (examples cited in Question #6 References [1-10]).

Metrology is a second discipline that has enhanced the science of firearm and toolmark identification. Metrology is the science of measurement. In order to use computer pattern recognition algorithms to compare toolmarks, the toolmarks must be accurately measured. This is where the metrology scientists have (and will) help the forensic community evaluate and implement the best technology for the task at hand (examples cited in Question #6 References [11-18]).

We believe the firearms and toolmark examiner community, in collaboration with the disciplines above, has a good understanding of the problems and potential solutions facing our profession. The problem is finding time and funding to conduct the necessary research. The vast majority of the research published in forensic science journals is based on volunteered time and conducted by a few dedicated individuals. This country would be wise to implement a broader source of forensic science research funding (e.g. NSF and NIH). One way to accomplish this task would be to increase the research funding already provided by the NIJ. If the goal is to have forensic science research move forward faster, forensic science research needs to be a viable full time career option.

Clifford Spiegelman, Distinguished Professor Texas A&M U

Yes. IR technology. More science based grants and contracts to universities and industry.

Brandon Giroux, President, Association of Firearm and Tool Mark Examiners (AFTE)

Q6 Part 1: Are there scientific and technology disciplines other than the traditional forensic science disciplines that could usefully contribute to and/or enhance the scientific, technical and/or societal aspects of forensic science?

For many years the Firearm and Toolmark community has been left to their own intrigue and dedication to investigate unanswered questions within the discipline as the primary source of research. However, as will be seen in the literature that is cited in this response, one will see that collaboration with Universities and research scientists has become more prevalent. Iowa State University, John Jay College, University of California at Davis are just a few of those universities that have taken up specific research in the field of Firearm and Toolmark Examination. NIST researchers have also contributed significantly to this research effort.

In the most recent history of research within the discipline, our profession has begun collaboration with computer scientists utilizing machine learning algorithms. Machine learning is a sub discipline of computer science that seeks to teach computers how to recognize (and compare) patterns. Since the comparison of toolmarks is the comparison of patterns, the collaboration between firearms and toolmark examiners and machine learning computer scientists is a collaboration that has started to produce interesting research papers.

Metrology is a second discipline that has enhanced the science of firearm and toolmark identification. Metrology is the science of measurement. In order to use computer machine learning algorithms to compare toolmarks, the toolmarks must be accurately measured. This is where the metrology scientists have (and will) help the forensic community evaluate and implement the best technology for the task at

hand.

Q6 Part 2: What mechanisms could be employed to encourage further collaboration between these disciplines and the forensic science community?

The Organization of Scientific Area Committees, established by the National Institute of Standards and Technology (NIST) has as a primary goal to answer this very question. The majority of forensic science disciplines have now been brought together within one entity with a purpose of establishing scientifically sound standards of practice within each discipline. The ability to share knowledge and research and to collaborate between like disciplines is now a greater possibility, which will only serve to enhance the technical and societal impacts of forensic science.

Shaku Teas, Forensic Pathologist

Biomechanical engineering.

American Academy of Forensic Sciences (AAFS) Board of Directors

Forensic science researchers are aware of research outside of the traditional forensic science disciplines and attempt to harness them as they see fit. In order to do this, forensic scientists have not been reluctant to collaborate. The emphasis should really be how to strengthen the forensic science research community. A stronger research community would be quicker to reach outward.

Jill Spriggs, President, CA Association of Crime Lab Directors

There is much to be gained by forensic scientists working with scientists in other fields to bring useful techniques to bear in forensics. A national forensic research budget is needed, which will stimulate cooperative efforts between forensic laboratories, universities and other scientific establishments.

Randy A. Sandifer, Forensic Scientist, American Academy of Forensic Sciences

Yes, Forensic Engineering. I feel that the aspect of forensic engineering should be expanded and added to the forensic community.

Other

Question 7 - Additional comments

Steven Johnson, Board Chair - The International Association for Identification

The bottom line in all the recommendations from the National Academy of Sciences to PCAST is there needs to be significant funding to support training, research, accreditation and certification of FSSPs. If the federal government wished to mandate certification and accreditation, it will come with a cost.

C. Michael Bowers, odontologist. Ventura Medical Examiner

Councils with merely advisory powers will be ineffective in establishing organizational change. Consider the NAS 2009 Report, and the NFSC as examples. Thanks for the opportunity to express these issues. Mike Bowers DS JD

Joe Cecil, Senior Research Associate; Division of Research; Federal Judicial Center

I am a strong proponent of strengthening the scientific integrity of the forensic sciences. I served on the National Academies' forensic science committee that prepared the 2010 report, and having developed the Federal Judicial Center/National Academies Reference Manual on Scientific Evidence, including overseeing

the development of a chapter for federal judges on forensic science by Paul Giannelli (attached). I am presently designing judicial education programs on for federal judges on forensic sciences. So, I have given these matters quite a bit of thought. Frankly, I am not sure that PCAST has much of a constructive role to play at this particular point in time. There have been notable improvements in some areas of forensic science science the 2010 National Academies report, though progress has been uneven. Among notable accomplishments are the following: (1) establishment of the National Commission on Forensic Sciences, which is about to announce its recommendations; (2) restructuring of the old Scientific Working Groups to be more effective in monitoring individual areas of forensic sciences; (3) strengthening of the FBI forensic science standards, including the recent announcement that their hair analysis standards were wrong; (4) the The U.S. Army's Defense Forensic Science Center decision to change in its practice of reporting a positive association between a latent fingerprint and an exemplar, and no longer "use the terms 'identification' or 'individualization' in technical reports and expert witness testimony. The American Association of Forensic Science, the American Bar Association, the Federal Judicial Center, and other professional associations are preparing training programs for judges and attorneys on forensic science issues. The National Commission will encourage further training on these issues.

So what will PCAST contribute to this effort at this time? Better to wait to see the reaction to the National Commission's recommendations and then decide how to weigh in. What is not needed is for PCAST to condemn forensic scientists at this time when a progressive group within the forensic science community is struggling to improve the quality of scientific practice within the forensic science community.

Nor will it be useful for PCAST to appeal directly to federal and state court judges to take the lead in this initiative. Judges will rely on the information provided by the attorneys, so attorney education is the most effective point of entry to strengthen this process.

Frederick R. Bieber, Professor, Harvard Medical School

The increasing use of forensic methods and the increased public awareness of the strengths and weaknesses of some scientific comparisons have put the forensic community at a crisis and crossroads. More academic scientists are needed to have input into the day-to-day workings of crime labs. The level any type of education of crime lab staff needs to be enhanced. More doctoral level scientists are sorely needed. Crime labs should have the opportunity to partner with universities and other companies to innovate. Finally, follow-up studies of the effectiveness of forensic policy is needed to determine how to improve existing methods.

Ahmed, PhD genetic engineering /DNA fingerprint

Yes there are many scientific and technology that could usefully in legal cases

Mary Beth Hauptle, Forensic Odontologist, FCMEO

Recent meetings by the Texas Forensic Sciences Commission have addressed issues inherently lacking in bite mark analysis.

Melissa Connor, Director, Forensic Investigation Research Station

Better education remains key. In western Colorado, the vast majority of practitioners have a bachelors, some have an associate's degree. Coroners and coroner deputies may only have a high-school education. A master's degree is a rarity, PhDs are non-existent.

Understanding Bayesian statistics, when basic math is an issue, is not going to happen.

Femblix Meek Tom Jr, Student Citizencorps.gov AAFS.ORG Fvtc.edu Dna.gov Wvu.edu Bronx Community College AAFS.org

The General Section was founded in 1968 and is the third largest section in the Academy. It is the home of established areas of forensic science not fitting into the more narrow definitions or membership requirements of the other sections, newly emerging forensic scientific specialties, or those forensic specialists whose numbers are not sufficient to support a separate section.

Eric Warren, Ph.D., Director, Special Agent/Forensic Scientist, Tennessee Bureau of Investigation

I am sure I am missing some very important citations off of the top of my head. For more literature regarding the scientific foundations (both empirically tested in the field and tested in a laboratory) of the FA/TM ID field, please see the AFTE or SWGGUN response to the 2009 NAS report and to the Subcommittee on Forensic Science's Research, Development, Testing & Evaluation (RDT&E) Interagency Working Group (IWG) solicitation (attached).

Robert Gaensslen, Prof Emeritus, Univ of Illinois Chicago

It is good that you are showing an interest in these questions.

Dr. Sushil Kumar Sharma, Editor EC Chemistry, UK

The International Collaborations can help.

Robert White, Forensic Chemist

How ridiculous it is to not have Forensic personnel on the board. I am available. Robert White

Michael Kusluski, Forensic Scientist, Michigan State Police

I appreciate the fact that you asked for my opinion. But in recent years, too many people have been talking AT the forensic community, rather than TO it. Many of the questions here do not seem like survey questions, but simple research questions. It makes me wonder if you are simply avoiding talking to our discipline.

Dr. L. Thomas Johnson, Professor (Retired) Marquete University

Replication of Known Dental Characteristics in Porcine Skin:
Emerging Technologies for the Imaging Specialist NIJ 2010-DN-BX-K176
Was foundational research. The data set needs to be expanded to a data base and the research reproduced to establish accuracy and reliability.

Howard A. Harris, Professor Emeritus

Forensic science has suffered from benign neglect and scientific snobbery. Ignorance about the adversarial nature of the legal system makes those with little knowledge and experience give credibility to legal advocates who are much more interested in "winning" than the interests of "JUSTICE"

Dr Geoffrey Stewart Morrison, Independent Forensic Consultant; Adjunct Associate Professor, Department of Linguistics, University of Alberta

My former titles and affiliations include:
Scientific Counsel, Office of Legal Affairs, INTERPOL General Secretariat; Director, Forensic Voice Comparison Laboratory, School of Electrical Engineering & Telecommunications, University of New South Wales; Chair, Forensic Acoustics Subcommittee, Acoustical Society of America.
Any opinions I express are my own and do not necessarily represent the opinions or policies of any of the

organizations with which I am or have been affiliated. A formatted version of my text is provided as File 1: "PCAST forensic science questions - GSM - 2015-12-04a.pdf".

Dr Rachel Bolton-King, Award Leader for Certificates of Professional Competence & Lecturer in Forensic Investigation, Staffordshire University

With the indicative size of the boxes and with the publication recently in press which typically contextualises my comments (and attached) I have tried to keep my answers quite brief. However, if you would like further information regarding research in this field I would be happy to discuss.

Carl C. Stacy - Director of Forensic Sciences/Chief Medical Examiner, University of Missouri Columbia, School of Medicine

Thank-you for your interest in what we do as forensic pathologists.

Mary K. Mainland, MD - Chief Medical Examiner, FL District 13

The shortage of forensic pathologists is partly due to the unique characteristics of the discipline (one works with deceased bodies) and in a large part, due to poor compensation. At our institution, pathology residents get excited about the field, only to discover that most, if not all, of the pathology subspecialties pay a great deal more. The discipline needs to be made much more lucrative in order to attract more pathology residents. More medical examiner postions are needed, both to deal with the current overload of cases and to replace coroners, who have little to no training in medicine or medicolegal death investigation. If you were murdered, whom would you prefer examined your body: an 18-year-old kid who works at the local video store, or a physician with a minimum of 8 years of training?

Bridget Lewis - President, International Association for Identification

A single clearinghouse for all forensic science research and references should be established. This would help avoid duplication of effort. There are many different professional associations, journals, research groups, etc., out there. If one entity could collect, store, and organize information and make it available to researchers, practitioners, and the legal community, that would be invaluable. This would have to include the federal forensic science laboratories that are often not able to share their information due to internal policies.

Forensic Comparative Examinations are about comparing impressions/images/objects. Comparative science can be generalized across the traditional forensic science disciplines. Simply stated, we need to study the objects in question and study impressions or images made from those objects. Then, study the ranges of levels of details being measured in those impressions/images/objects. Study the measurements that are being made during training in competency and proficiency tests. And, study uncertainty of measurement within the human examiner as comparative measurements are being made. We need to study results of those comparative examinations, all while using known source ground truth impressions/images/objects. We also need to study when an inconclusive decision is the correct decision with a forensic comparative examination.

University researchers with forensic scientist collaborators are needed for studying the comparisons of impressions or images of traditional and non-traditional objects. Fracture examinations of objects encompass such a wide variety of things that this discipline would be ideal for studying and understanding generalizations. The Comparative Science disciplines should be considered more similar to each other than dissimilar. This can be in the examination process across the many traditional disciplines. The disciplines are more alike than perceived by many people. The structure of OSAC emphasizes this generalization by

grouping similar disciplines together:

See: http://www.nist.gov/forensics/upload/OSAC-Block-Org-Chart-3-17-2015.pdf or http://www.nist.gov/forensics/osac/index.cfm

This is the official opinion of the International Association for Identification as composed by its Forensic Comparative Examination Committee and endorsed by President Bridget Lewis.

Paul L Morrow - Forensic pathologist, Auckland, NZ, formerly Chief Medical Examiner, Vermont

It is essential not to confuse technologies and techniques with the practice of diagnostic medical Science. Technologies and techniques are the tools employed in expert medical (forensic pathological) diagnosis but are not the diagnostic process itself, which is th practice o forensic pathology. How to evaluate a technique or technology is not the same as how one evaluates the practice of medical diagnosis.

Eoghan Casey, Multiple titles and affiliations related to digital forensics and cyber investigation

Increased recognition of digital evidence as a discipline of forensic science could help bring much needed support and funding to address the questions raised by PCAST.

We encourage PCAST to engage with digital forensic researchers and practitioners to improve reliability of and confidence in digital forensic results.

Michele Catellier, MD, Associate Medical Examiner, State of Iowa

As forensic science is becoming more recognized, both for it's contributions to analysis of crime and identification (or exoneration) of possible perpetrators, the area of forensic medicine is poorly understood. It is often lumped with "forensic sciences" with regard to the quality controls and protocols that are necessary within the laboratory environment. This is in error. At the same time, there are fewer and fewer trained medical doctors, Forensic Pathologists, who are available in the workforce. These are the professionals who perform autopsies and evaluate injury patterns, both in the dead and the living. We determine the presence (or absence) of injury, medical disease, and illness. In addition, we have the skills to interpret injury patterns and differentiate injury from artifact. With the retirement of many forensic pathologists, the already short supply is becoming more pronounced. Medical students often are not aware of this specialty, but when they are, they often choose another area of expertise, as the compensation is not commensurate with the educational investment. In addition, scrutiny by non-medical oversight teams often create a negative work environment by attempting to control the medical management of the physicians by application of science laboratory limitations and controls. Research in forensic pathology is limited. Of course, one reason for that limitation is that our "subjects" are humans, not laboratory specimens. Another reason is that with fewer forensic pathologists to manage the sudden and violent deaths in our jurisdictions, there is little time to devote to non-autopsy (i.e., research) work. Finally, the funding is quite limited with respect to support of forensic medicine research. Forensic pathologists should be represented more in councils that evaluate forensic science. In addition, forensic pathologists should be better compensated, and better advertised, so that more medical students will consider this a viable career choice.

Michele Triplett, Forensic Operations Manager-King County Regional AFIS

Accessibility of Evidence Even more important than the method, a criterion for conclusions, and accuracy rates, is the accessibility of evidence for defense attorneys. Pattern evidence conclusions may be very accurate but errors do occur. The defense has had an extremely difficult time gaining access to evidence so they can have the evidence reviewed. The stone walling has led to innocent people spending years and decades wrongly incarcerated. Lana Canen spent 8 years in prison in Indiana, and Beniah Alton Dandridge

spent 21 years in prison in Alabama because the courts and the police agencies would not release evidence. In both cases, once the evidence was released, the conclusions were found to be in error (i.e., the supporting justification behind the conclusion did not support the conclusion). To protect against errors, evidence needs to be quickly and easily accessible to the defense for review. Federal laws need to be enacted to ensure this type of thing does not happen in the future.

Michael T. Beddow, Forensic Scientist IV, Phoenix Police Department Crime Laboratory

Many of the critics (regardless of their area of expertise) of Forensic Firearm and Toolmark Examination constantly focus on the matters of subjectivity and expert opinion. I would like to take a moment and share my thoughts on this matter. There is no science be it chemistry, physics, engineering or any other hard science where the scientists opinion comes across in the results and conclusions of a single analysis or complete research endeavor. Whether it is a chemist's interpretation of an GCMS chromatogram or a biologist interpreting the results of a genetic analysis, or an engineer's failure analysis, all of the scientists associated with these analyses are going to provide their results in the form of an opinion based on each of the individuals' objective application of their particular field of science and the scientific method in general. This is no different with the science of FORENSIC FIREARMS EXAMINATION. Over the past one hundred years we have utilized the scientific method, in conjunction with many different scientific disciplines, to develop scientifically sound and legally accepted methods for the evaluation of firearm and toolmark related evidence. These methods have been continually researched and tested in the furtherance of our quest for knowledge and justice. With each repeated and or newly conducted research project, the primary methods and foundations utilized by Forensic Firearms and Toolmark Examiners are reaffirmed; this only serves to bolster our position that our field is routed in sound science and methodologies. The absence of a simple mathematical equation or electronic print out to provide a result (still in need of interpretation) make our field no less scientific than any others.

Andy Smith, Chair - Firearm/Toolmark Subcommittee NIST OSAC

Thank you for allowing an opportunity to share the valuable research that has been conducted and continues to be conducted in the Firearms and Toolmarks Discipline of Forensic Science. Should you need any further clarification do not hesitate to contact me at the email address I have provided.

Clifford Spiegelman, Distinguished Professor Texas A&M U

Mainstream scientific standards need to apply. Results need to be published in mainstream science journals rather than trade journals to be used in court.

Brandon Giroux, President, Association of Firearm and Tool Mark Examiners (AFTE)

On June 14, 2011, AFTE submitted a 94 page response to 25 foundational questions on firearm and toolmark examination submitted by the Subcommittee on Forensic Science (SoFS), Research, Development, Testing, & Evaluation Interagency Working Group (RDT&E IWG). This response consisted of a compilation of numerous references, with abstracts, that AFTE felt provided the scientific underpinnings of forensic firearm and toolmark identification. The entire document can be accessed by going to the AFTE website and looking under the "Resources" tab and then "AFTE Position Documents".

The SoFS RDT&E IWG felt that if a forensic specialty, like firearm and toolmark identification, could respond to their 25 questions by providing sound, peer-reviewed, references that they probably rested on firm scientific underpinnings. AFTE was one of the first, if not the first, to provide an underpinning compilation list to the RDT&E IWG.

The SoFS RDT&E IWG intended to have someone evaluate these articles to determine whether or not they actually did provide a firm scientific underpinning. However, despite good intentions, they were not able to have this evaluation done prior to the expiration of their charter.

In late 2014 or early 2015, however, it was announced that the American Association for the Advancement of Science (AAAS) had been funded to conduct a quality and gap analysis of the underpinning compilations submitted to the SoFS RDT&E IWG by ten forensic disciplines, including firearms and toolmarks. To date, there has been no public announcement regarding the state of these evaluations by AAAS.

We have attached the letter written to AAAS, a copy of the cover letter the entire compilation provided by AFTE to SoFS/RDT&E IWG.

American Academy of Forensic Sciences (AAFS) Board of Directors

There are many promising advancements that could have applicability to criminalistics-based disciplines in the near future. However, there seems to be a disconnect between research and practice. Crime labs are far more concerned with accreditation and quality assurance issues than implementation of new technologies, which often hinders research.

For example, the vast majority of forensic odontologists in the US are dental practitioners with private dental practices, who have expended considerable time, effort and money to become trained and further educated via week to year long continuing education courses and various workshops offered by the AAFS, by the American Board of Forensic Odontology and the American Society of Forensic Odontology. Odontologists are not typically employed by a dental school, medical school or forensic laboratory on more than a consultant or part time/contract as needed basis, nor have salaried release time available to them for odontology research. Forensic Odontology is a necessary service for Law Enforcement/Coroner/Medical Examiner/District Attorney, but budgetary restraints keep it generally on an “As needed basis”.

Shaku Teas, Forensic Pathologist

Head trauma and fractures in infants and children are a highly controversial and needs more research. The literature should be re-evaluated and we need prospective studies to evaluate other causes of subdural hemorrhage and retinal hemorrhages

Randy A. Sandifer, Forensic Scientist, American Academy of Forensic Sciences

I feel that the best way to strengthn forensic science is the reorganization of training and professional licensure. Professional Licensure does not exist in certain areas of forensic science. I think it would be a great benefit for all sides to have professional licensure. I have enclosed a written journal proposing this idea. The title of the journal is The Missing Link.

Consortium on Forensic Science Organizations

We wish to also take this opportunity to bring the following to the attention of PCAST and OSTP:

- The NAS report was not a comprehensive review or evaluation of research related to forensic science;
- There have been significant efforts since the NAS report to catalog and evaluate forensic research;
- There are challenges in providing a valuable literature search and review to PCAST;
- Support is needed for forensic labs and scientists to publish more of the available data supporting the scientific foundation of forensic science disciplines;
- Changes are needed to the federal research strategy regarding forensic science;
- Forensic practitioners and leaders need to be involved in the national policy decision process.

2009 NAS Report

The current PCAST effort seems to start with the 2009 National Academy of Sciences (NAS) report, which the forensic science practitioner community views as being more harsh in its criticism than what is truly deserved. We believe there was a greater scientific basis for forensic science practice than what was appreciated then. Further, the intent of the 2009 NAS effort was never to provide an evaluation of all of the foundational research available to support each forensic science discipline. An effort to catalog and valuate all the available research is almost impracticable. Accordingly, to focus exclusively on the forensic scientific literature since 2009, will miss some important foundational literature. It is important to the forensic science community that the current PCAST effort is not dismissive of the collective body of research related to forensic science before and after 2009. The literature is vast and growing and should not be dismissed. Nonetheless, the NAS report did appropriately point out that more scientific research would be useful and that, in particular, the patterned evidence disciplines deserved more attention.

Efforts Since the 2009 NAS Report

Several efforts have been launched since the NAS report to address these research gaps. This is noted in your February 2014 report, Strengthening Forensic Science: A Progress Report (https://www.whitehouse.gov/sites/default/files/microsites/ostp/forensicscience_progressreport_feb-2014.pdf), but we would particularly like to point out the following:

- The Laura and John Arnold Foundation has funded the American Association for the Advancement of Sciences (AAAS) to conduct a study, *Forensic Science Assessments: A Quality and Gap Analysis*, to review the forensic science literature to reveal areas for further research need (http://www.aaas.org/page/forensic-science-assessments-quality-and-gap-analysis). They will initially study fire investigation, latent print analysis, and firearms and toolmarks, but will then move to bitemark analysis, hair analysis, bloodstain pattern analysis, and others.
- The AAAS effort developed out of the Research, Development, Technology and Evaluation (RDT&E) Interagency Working Group of the OSTP Subcommittee on Forensic Science, which itself had attempted to collect the foundational literature for many of the pattern evidence disciplines (i.e. https://afte.org/uploads/documents/position-rdte-iwg-2011.pdf, http://www.nist.gov/forensics/upload/Annotated-Bibliography-Odontology.pdf, http://www.nist.gov/forensics/upload/Annotated-Bibliography-Hair.pdf.
- The National Commission on Forensic Science (NCFS) has a Scientific Inquiry and Research subcommittee that has been studying the research and scientific literature in the field (http://www.justice.gov/ncfs/scientific-inquiry-and-research) —they have produced a work product and another has been out for public comment.
- The National Institute of Justice (NIJ) has a long standing Forensic Science Technology Working Group (http://www.nij.gov/topics/forensics/pages/forensic-operational-requirements.aspx) which brings leaders in the field together to discuss areas for further research and priorities for NIJ funding. As late as September 2015, they developed a twelve page listing of needs and requirements for research in the field (http://www.nij.gov/topics/forensics/documents/2015-forensic-twg-table.pdf). The recently published 2015 NAS report, *Support for Forensic Science: Improving the scientific role of the National Institute of Justice*, made recommendations for improving NIJ grant funding.
- The National Institute of Standards and Technology (NIST) has established a Center for Statistics and Applications in Forensic Evidence (CSAFE) which will focus on pattern evidence (http://www.nist.gov/coe/forensics/). This group is also collecting literature and research supportive of pattern evidence disciplines.
- The NIST Organization of Scientific Area Committees (OSAC)'s Physics and Patterned Evidence Scientific Area Committee is reviewing standards in this area.

- The first NIST International Symposium on Forensic Science Error Management was held on July 21-24, 2015.
- NIJ has established a Forensic Science Center of Excellence to assist in
- technology transfer and forensic science education and training.
- Thousands of papers have been published in the forensic sciences since 2009.

Federal Research Efforts

Instead of duplicating the efforts of others in this area or perhaps becoming mired down in an untenable task for a twelve month period, the CFSO believes that PCAST could better focus their efforts in support of the forensic sciences by specifically pointing out the inadequate forensic science research base funding. This could do more to enhance the scientific base than any other single effort. The NAS report on NIJ forensic science specifically noted that research and development (R&D) funding levels have declined since 2010. The primary federal R&D funding agencies (NIH, NSF, NASA, DOD DOE, USDA) do not include DOJ (<1% of the federal R&D portfolio; $112M of $130T; NSF R&D Report FY2013 to 2015 and NSF R&D Funding Drop Brief). While we appreciate and support the research efforts of federal laboratories, the current funding mix within the forensic sciences is heavily weighted to applied research at federal crime laboratories and very little to university research; this is in sharp contrast to R&D in other sectors. In general, research universities receive 13% of the private and governmental expenditures, but 56% of the basic science research (http://files.eric.ed.gov/fulltext/ED517265.pdf). The R&D spending in forensic science is further diluted by social science research and research grants that go outside forensic science departments. The calls for research by basic researchers outside of the existing forensic science academic community serves to dilute and undermine the funding of the forensic science academic community itself, which is the greater need. It is currently not possible for a university research career in forensic science based upon existing levels of funding available for sponsored forensic science research. A core group of forensic science researchers at universities must be developed. This requires stable sustained funding available to support the academic enterprise. It is also virtually impossible for forensic science departments to acquire any equipment on forensic science research grants. Without a university research base the foundational science for the forensic sciences will continue to lag. Without significant active R&D in forensic science programs, students are not adequately exposed to research and a research culture. Furthermore, the federal government funds research and technology transfer primarily through universities, but this does not appear to be the case with regard to forensic science. This is an issue that has not received sufficient attention and yet is fundamental to confidence and progress in forensic science. In fact, this could be conceived as an issue of national security given the role that forensic science has come to play in criminal justice, civil rights, terrorism, and intelligence issues.

Although NIJ is the primary research grant funding agency in the forensic sciences, other agencies should be encouraged to more actively engage in forensic science research efforts. The ongoing efforts at the Department of Commerce (NIST), Department of Justice (NIJ, OJP, DEA, FBI, BATFE, etc.), and the Department of Defense should be increased and others like the Department of Health and Human Services (NIH), Department of Energy (national laboratories), and Department of Homeland Security should direct more research into this space. This is not an exhaustive list and there is a need for other federal agencies such as the Department of Interior (wildlife forensics), Department of Treasury (financial forensics), Department of Transportation (NHTSA), Department of Agriculture (food safety), and Department of Education (education and training of forensic researchers and applied scientists) to increase their research programs related to forensic science. More involvement from the nation's most prestigious government research laboratories would be a welcome addition to the forensic science community. CFSO encourages networking of these federal research programs with the practitioners working at federal, state, and local laboratories. Many federal agencies have found great success by partnering with practitioners to perform

the research and inform the forensic science community about the results, conclusions, and implementations. The research efforts of these federal agencies should not be siloed. These entities should meet together regularly to discuss coordination of forensic science research efforts so the combined group is addressing the most serious issues, transferring information to the forensic science practitioners, and building off the research being done in other parts of the federal government.

A second reason for minimal research in academic forensic science programs is an absence of PhD students. Forensic science degrees are undergraduate or Master's level degrees. The Sam Houston State University has developed the first PhD in forensic science only this year. There are biology and chemistry PhD degrees with a forensic focus and there are some discipline specific PhDs such as UMD forensic toxicology programs and the UNT forensic molecular biology degree programs. Without PhD students, it is very difficult to have long-term, in-depth research programs. Master's students matriculate for only two years and can only commit to short term projects. In traditional university science programs, much learning is transferred from student to student over several years, but this is simply not possible in most existing forensic science programs. Again, it is difficult to inculcate a scientific cultural without such PhD student-based infrastructure.

Continue to Engage the Forensic Scientists

The next generation of techniques and tools that will be used in the nation's crime laboratories need to be researched and developed. We believe that more research will always be needed to solidify and strengthen all forensic science disciplines, and finding and funding the research needs is critical. We applaud your efforts to reach out and engage crime laboratory leaders and practitioners to understand these issues. We encourage even more outreach and offer resources such as tours of our laboratory and Medical Examiner facilities, shadowing practitioners, and further dialog with all of our member organizations. One of the biggest criticisms from the forensic science practitioner community regarding the 2009 NAS report was the minimal involvement from practitioners. Efforts ongoing at the NIST OSAC demonstrate that practitioners are very interested in the scientific basis and standards related to forensic science practice. Partnership and collaboration with the federal, state, and local practitioners during the development of federal policy initiatives will lead to more rapid and wide-spread implementation in the forensic science community.
We appreciate the efforts of OSTP and PCAST to address this critical issue and we look forward to engaging with OSTP and PCAST on a more robust federal research agenda related to forensic science. We anticipate more opportunities to discuss the critical report that will go to President Obama on this issue and offer our assistance in this endeavor.

Matt Johnson

Footwear examination relies heavily on traditional side-by-side comparison methods.
One scientific technology that can be efficiently used to enhance footwear comparisons is the use of an eye-tracker. For example, an eye tracker would allow the examiner to track his or her gaze behavior while evaluating footwear evidence and looking for similarities in known and questioned impressions. To illustrate, fixations on both known and questioned impression can be recorded separately, and then later merged and analyzed to construct a heat map that allows the examiner to see areas of emphasis (Busey et al., 2011).

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Duplicate submissions have not been deleted.

DNA

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Bitemarks

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