The Association of Firearm and Tool Mark Examiners (AFTE) December 23, 2015 response to seven questions related to forensic science posed on November 30, 2015 by The President's Council of Advisors on Science and Technology (PCAST):

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.

https://afte.org/resources/swggun-ark

The following are literature citations, all published within the last five years, for the more important studies that qualify as material principally concerned with the validity of firearm and toolmark identification. A short summary follows each citation.

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and that a large body of confirmatory evidence from training programs, experimentation, etc., will forever remain unpublished.

Testability of the Scientific Principle

Firearms Identification, Bullets

Hamby, J, et al, "The Identification of Bullets Fired From 10 Consecutively Rifled 9MM RUGER Pistol Barrels – A Research Project Involving 619 Participants from 23 Countries Using Optical Comparison Microscopy and 'Ballistics' Imaging Instrumentation with an Analysis of Possible Error Rate Using Bayesian Statistics", Journal of Forensic Sciences (In Press) 2015

Ten consecutively rifled RUGER P-85 pistol barrels were obtained from the manufacturer and then test fired to produce known test bullets and 'unknown' bullets for comparison by firearms examiners from around the world. This study is a continuation of one originally designed and reported on by David Brundage. The original study was primarily limited to examiners from nationally accredited laboratories in the United States and we wanted to expand the study to provide test sets for firearms examiners around the world. The RUGER P-85 pistol and the 10 consecutively rifled barrels were borrowed from the Illinois State Police. Ammunition was obtained from the Winchester Ammunition Company (A Division of Olin), and 240 tests sets produced and distributed to forensic scientists and researchers around the world. A thesis, which involved a total of 201 participants – including the original 67 reported on by Brundage - was published by Hamby in 2001. This paper reports on the final conclusions of the research conducted by Brundage, Hamby and Thorpe over a 15-year period. Recently, 20 additional test

sets were manufactured using a 4th type of 9mm Luger ammunition and polymer 'clone' sets made as well. These sets – both actual bullets and clone sets – have been distributed for use in forensic laboratories worldwide. (Note- Currently this research project has a total of 653 participants from 31 countries)

Chu, et al., "Automatic Identification of Bullet Signatures Based on Consecutive Matching Striae (CMS) Criteria", Forensic Science International, Volume 231, 2013, pp. 137-141.

This paper described a study of fired bullet markings from ten consecutively manufactured firearm barrels by an automated 3D signature analytic method. This study used 3D topography image capture technology with acquisitions that were cross-correlated to existing firearm Consecutive Matching Striae (CMS) identification criteria. Results provided a fairly objective test that demonstrated support for these firearm CMS criteria.

Wong, C., "The Inter-Comparison of 1,000 Consecutively-Fired 9mm Luger Bullets and Cartridge Cases from a Ruger P89 Pistol Utilizing both Pattern Matching and Quantitative Consecutive Matching Striae as Criteria for Identification", AFTE Journal, Volume 45(3), Summer 2013, pp. 267-272.

Previous studies have investigated the effect of consecutive firing of firearms to determine how the wear on barrels and breechfaces would affect the identification of fired bullets and cartridge cases. This study was conducted to determine if the toolmarks on fired bullets and cartridge cases would change significantly after firing 1,000 cartridges through a Ruger P89 9mm Luger semiautomatic pistol, while using both pattern matching and quantitative consecutively matching striae (QCMS) as identification criteria during the comparison process. While there were some differences between the toolmarks on the bullets and cartridge cases throughout the firing sequence, each bullet and cartridge case was successfully identified to the first bullet or cartridge case.

Mikko, D., et al., "Reproducibility of Toolmarks on 20,000 Bullets fired through an M240 Machine Gun Barrel", AFTE Journal, Volume 44, Number 3, Summer 2012, pp. 248-253.

This article discusses the reproducibility of toolmarks on 7.62mm high velocity bullets fired through a single M240 machine gun barrel. Over the years, there have been several research studies and published articles pertaining to consecutively manufactured rifled barrels and the ability to microscopically identify bullets as having been fired through the same barrel of a firearm; however, to the knowledge of the authors, there has not been any in-depth microscopic study pertaining to 20,000 bullets being fired through a single rifled barrel and subsequently identified to that particular barrel. This study was designed to provide credible evidence in regards to the reproducibility and uniqueness of striations on the bearing surfaces of fired bullets. Despite changes to the reproducibility of some of the individual markings over the course of the study, the authors were able to correctly identify the barrel of origin for each of the collected fired bullets. See subsequent related article: Mikko, D. and Miller, J., "An Empirical Study/Validation Test Pertaining to the Reproducibility of Toolmarks on 20,000 Bullets Fired

Through M240 Machine Gun Barrels", AFTE Journal, Volume 45, Number 3, Summer 2013, pp. 290-291.

Mikko, D. and Miller, J., "An Empirical Study/Validation Test Pertaining to the Reproducibility of Toolmarks on 20,000 Bullets Fired Through M240 Machine Gun Barrels", AFTE Journal, Volume 45, Number 3, Summer 2013, pp. 290-291.

This article is a follow-up to an article that was published in the AFTE Journal-Volume 44, Number 3-Summer 2012, titled "Reproducibility of Toolmarks on 20,000 Bullets fired through an M240 Machine Gun Barrel". Using a second M240 Machine gun with its original barrel, along with a new spare barrel assembly, thirty (30) additional bullets were test fired through both barrels and subsequently inter-compared blindly by four firearm and toolmark examiners, one of which had just completed his formal two-year training period. Additionally, the recovered (60) test fired bullets from both barrels were also mixed with the 127 bullets recovered during the test firing of 20,000 bullets in the reproducibility study and examined by the four firearm and toolmark examiners in a blind test study, in order to determine whether or not the examiners could correctly identify or eliminate the bullets as being fired through the correct barrel. A total of 164 questioned fired bullets were examined, which resulted in 164 correct answers from the participants in the study (zero percent error rate).

Fadul, T. G., "An Empirical Study to Evaluate the Repeatability and Uniqueness of Striations/Impressions Imparted on Consecutively Manufactured Glock EBIS Gun Barrels", AFTE Journal, Volume 43, Number 1, Winter 2011, pp. 37-44.

This paper describes an empirical study of ten consecutively manufactured Glock barrels containing the Enhanced Bullet Identification System (EBIS). Study consisted of test sets sent to 238 examiners from 150 laboratories in 44 states and 9 countries that were designed to test the examiner's ability to correctly identify fired bullets to the barrel that fired them. The results from 183 of these examiners produced an error rate of 0.4%. This study validated the repeatability and uniqueness of striated markings in gun barrels, as well as the ability of a competent examiner to reliably identify fired bullets to the barrels that marked them.

Intelligent Automation, Incorporated, "A Statistical Validation of the Individuality of Guns Using High Resolution Topographical Images of Bullets", National Institute of Justice Grant #2006-DN-BX-K030, October, 2010

This was a study of marks on fired bullets by a topography based (3D) automated system. This study continued the analysis of a previous 2005 NIJ bullet study and validated the original premise of Firearm/Toolmark ID. This study also concluded that 1) the ability to determine that a given bullet was fired from a specific barrel depends on the individual barrel itself and not only on the brand of its manufacture, and 2) the performance of the automated analysis system used in this study is not representative of that of a trained firearms examiner as humans have a remarkable ability to perform pattern matching that is difficult to be replicated in any automated system.

Firearms Identification, Cartridge Cases

Hamby, J., et al, "Evaluation of GLOCK 9mm Firing Pin Aperture Shear Mark Individuality Based On 1,632 Different Pistols by Traditional Pattern Matching and IBIS Pattern Recognition", Journal of Forensic Sciences (In Press) 2015.

Over a period of 21 years, a number of fired GLOCK cartridge cases have been evaluated. A total of 1,632 GLOCK firearms were used to generate a sample of the same size. Our research hypothesis was that no cartridge cases fired from different 9-mm semi-automatic GLOCK pistols would be mistaken as coming from the same gun. Using optical comparison microscopy, two separate experiments were carried out to test this hypothesis. A sub-sample of 617 test fired cases were subjected to algorithmic comparison by the Integrated Ballistics Identification System (IBIS). The second experiment subjected the full set of 1,632 cases to manual comparisons using traditional pattern matching. None of the cartridge cases were "matched" by either of these two experiments. Using these empirical findings, an established Bayesian probability model was used to estimate the chance that a 9-mm cartridge case could be mistaken as coming from the same firearm when in fact it did not (i.e. the random match probability).

Baldwin, D.P., et al., "A Study of False-Positive and False-Negative Error Rates in Cartridge Case Comparisons", USDOE Technical Report # IS-5207 (April 7, 2014)

This report provides the details for a study designed to measure examiner (not laboratory) error rates for false identifications and false eliminations when comparing an unknown to a collection of three known cartridge cases. Volunteer active examiners with Association of Firearm and Toolmark Examiners (AFTE) membership or working in laboratories that participate in ASCLD were provided with 15 sets of 3 known + 1 unknown cartridge cases fired from a collection of 25 new Ruger SR9 handguns. The ammunition was all Remington 9-mm Luger (manufacturer designation L9MM3) and sets were made up of cartridge cases fired within 100 cartridges of each other for each gun. During the design phase of the experiment, examiners had expressed a concern that known samples should not be separated by a large number of fired cartridges. However, studies published on this effect indicate that several thousands of cartridges could be fired by the same firearm without making the identifying characteristics change enough to prevent identification. [1] Examiners were provided with a background survey, an answer sheet allowing for the AFTE range of conclusions, and return shipping materials. They were also asked to assess how many of the 3 knowns were suitable for comparison, providing a measured rate of how often each firearm used in the study produces useable, quality marks. The participating examiners were provided with known positives and known negatives from independent groups of samples, providing independent measurements of a false-positive rate and independent measurements of a false-negative rate, allowing the study to measure both rates and uncertainties in those rates.

Responses were received from 218 participating examiners. The rate of false negatives (estimated as 0.367% from comparisons known to be from the same firearm but reported as eliminations) was quite low with the error distributed across examiners of various backgrounds (state, federal, local, private, etc. as determined from self-reported survey information). The overall rate of false positives (estimated as 1.01% from comparisons known to be from different firearms but reported as identifications) was significantly higher. However, most of the errors

were reported by a small number of examiners; that is, individual examiners have varying error rates. For most examiners this is quite low while for some it is relatively high. Hence the overall rate is best interpreted as an average of widely varying individual rates. Inconclusive results were not recorded as errors. Rates of poor quality mark production for these handguns varied across the 25 sample handguns. Those rates were 2.3 (±1.4) %.

False-positive and false-negative error rates for individual examiner performance on comparisons were measured. The rates are not uniform across the sample population with a few examiners providing most of the false-positive responses. False-negative rates are low and comparable to or lower than the rate of production of poor quality marks by the firearms used in this study. Laboratory error rates may be significantly lower than these individual rates if quality assurance procedures are applied that can effectively manage to reduce or eliminate the propagation of false positives reported by individuals.

Stroman, A., "Empirically Determined Frequency of Error in Cartridge Case Examinations Using a Declared Double-Blind Format", AFTE Journal, Vol. 46(2), Spring 2014, pp. 157-175.

This paper describes a no-gun empirical study of fired cartridge cases to determine the frequency of error in firearms identification using a declared double-blind testing format; i.e., a declared test containing blind elements. Seventy-four of seventy-five examiners accurately identified the questioned fired cartridge cases to the respective known specimens with no false positives. This study also demonstrated that examiners were able to accurately evaluate breechface markings avoiding mis-identifications from substantial subclass marks borne by the cartridge cases.

Chu, Tong and Song, "Validation Tests for the Congruent Matching Cells (CMC) Method Using Cartridge Cases Fired with Consecutively Manufactured Pistol Slides", AFTE Journal, Volume 45(4), Fall 2013, pp. 361-366.

This was a study of ten (10) consecutively manufactured slides using 3D topography technology with correlations of paired breech marking correlation cells to establish firearm identifications. Test results showed significant separation between KM and KNM distributions without any false positive or false negative identification.

Fadul, et al, "An Empirical Study to Improve the Scientific Foundation of Forensic Firearm and Tool Mark Identification Utilizing Ten (10) Consecutively Manufactured Slides", AFTE Journal, Volume 45(4), Fall 2013, pp. 376-389.

Empirical study of marks produced from 10 consecutively Ruger brand manufactured pistol slides by 217 firearm examiners from 46 states and the District of Columbia. Results of this study established an error rate of less than 0.1%, and validated toolmark durability as these slides maintained their individual signature after multiple firings.

Stowe, A., "The Persistence of Chamber Marks From Two Semiautomatic Pistols on Over 1,440 Sequentially-Fired Cartridge Cases", AFTE Journal, Vol. 44(4), Fall 2012, pp. 293–308.

A Browning Hi-Power semiautomatic pistol and a Hi-Point Model C semiautomatic pistol were test fired a total of 1,440 times each, and their chamber marks were examined. Ammunition used included cartridges with cases made of aluminum, brass and nickel-plated brass. Microscopic examination of the chamber marks revealed that they were reproducible and identifiable up to 960 firings and that the metallic composition of the cartridge case does not affect the reproducibility of the chamber marks.

Petraco D. K., et al, "Application of Machine Learning to Toolmarks: Statistically Based Methods for Impression Pattern Comparisons", NIJ/NCJRS Document #239048, Award #2009-DN-BX-K041, July 2012

This was a statistical study that evaluated 3D quantitative surface topographies of toolmarks, consisting of fired cartridge cases, screwdriver and chisel striations, generated using confocal microscopy. Principal component and canonical variate analysis, as well as support vector machine methodology, was used to objectively associate these toolmarks with the tools that produced them. Estimated toolmark identification error rates were approximately 1% using these algorithmic methods. The findings of this objective and quantitative scientific research support the general conclusions codified in the AFTE Theory of Identification.

Weller, T. J., et al, "Confocal Microscopy Analysis of Breech Face Marks on Fired Cartridge Cases from 10 Consecutively Manufactured Pistol Slides", Journal of Forensic Sciences, Volume 57(4), July 2012, pp. 912-917.

This was a study of 90 test fired cartridge case specimens from ten consecutively manufactured pistol slides. A total of 8010 comparisons were conducted by using confocal microscopy with a 3D cross-correlation analysis logarithm. The average match scores were 0.82 with the average non-match scores 0.20. There was no overlap of scores between matching and non-matching test scores. This study provided objective data that supports the AFTE Theory of Identification.

Valle, F., et al, "Nanotechnology for Forensic Sciences: Analysis of PDMS Replica of the Head of Spent Cartridge Cases by Optical Microscopy, SEM and AFM for the Ballistic Identification of Individual Characteristics Features of Firearms", Forensic Science International, Issue 222, 2012, pp. 288-297.

A novel application of replica molding to a forensic problem, viz. the accurate reproduction of the case head of gun and rifle cartridges, prior and after being shot, is presented. The fabrication of an arbitrary number of identical copies of the region hit by the firing pin and the breech face is described. The replicas can be (i) handled without damaging the original evidence, and (ii) distributed to different law enforcement agencies for comparison against other evidence found on crime scenes or ballistics tests of seized firearms, (iii) maintained on a file in the laboratory. A detailed analysis of the morphological features was carried out using a variety of instrumentation.

Mayland, B. and Tucker, C., "Validation of Obturation Marks in Consecutively Reamed Chambers", AFTE Journal, Volume 44(2), Spring, 2012, pp. 167-169.

This study of fired cartridge cases from ten consecutively manufactured firearms was conducted to determine the reproducibility and reliability of obturation marks from reamed chambers for identification purposes. Results of this empirical study, which consisted of sixty-four (64) participants from nineteen (19) national laboratory systems, effected a sensitivity rating of 0.927. These results demonstrate that obturation markings imparted on fired cartridge cases can be used as a reliable means of identification to the firearm that marked them.

Saribey, A, and Hannam, A., "Comparison of the Class and Individual Characteristics of Turkish 7.65mm Browning / .32 Automatic Caliber Self-Loading Pistols with Consecutive Serial Numbers", Journal of Forensic Sciences, Volume 58(1), January 2012, pp. 146-150.

Firearms identification is based on the fundamental principle that it is impossible to manufacture two identical items at the microscopic level. As firearms manufacturing technologies and quality assurance are improving, it is necessary to continually challenge this principle. In this study, two different makes of 7.65mm Browning / .32 caliber self-loading pistols of Turkish manufacture were selected and examined. Ten pistols with consecutive serial numbers were examined and test fired 10 times. The fired cartridge cases were recovered for comparison purposes. It was found that for each make of pistol, the individual characteristics within the firing pin impression, ejector and breech face marks of all 10 pistols were found to be significantly different.

La Porte, D., "An Empirical Validation Study of Breechface Marks on .380 ACP Caliber Cartridge Cases Fired from Ten Consecutively Finished Hi-Point Model C9 Pistols", AFTE Journal, Volume 43, Number 4, Fall 2011.

An empirical study was conducted using ten (10) consecutively finished Hi-Point model C9 slides and one frame acquired from the Hi-Point Manufacturing Company in Mansfield, Ohio. The ten (10) slides were mounted on the frame and test fired to obtain cartridge cases for comparison. The test fired cartridge cases were microscopically examined, evaluated and compared for class and individual characteristics that resulted from the manufacturing process. Prominent striations were evident on each test-fired cartridge case. These resulted from sanding of the breech face. The variations that occur during the manufacturing process of sanding result in unique, identifiable, individual breech face marks devoid of subclass influence. A limited validation study was conducted after the empirical study. Correct associations were made during this limited study.

Thompson, R., Song, J., Zheng, A., and Yen, J., "Cartridge Case Signature Identification Using Topography Measurements and Correlations: Unification of Microscopy and Objective Statistical Methods", National Institute of Standards and Technology, Presented at the 18th European Network of Forensic Science Institutes (ENFSI) Conference, Lisbon, Portugal, October, 2011

A comparison microscope employing the standard optical comparison method and confocal microscopy, with subsequent cross-correlation topography analysis, were used to correctly identify cartridge cases fired from ten consecutively made pistol slides. Subsequent cross correlation function analysis and statistical analysis of match and non-match scores correctly identified the fired cartridge cases back to their respective known slide source in 19 of 20 occasions with one inconclusive result. Results of the mathematical determination of slide source were compared to the validated results from the microscopic comparisons.

Lightstone, L., "The Potential for and Persistence of Subclass Characteristics on the Breech Faces of SW40VE Smith & Wesson Sigma Pistols", AFTE Journal, Volume 42(4), Fall 2010, pp. 308-322.

An article published in the 2007 AFTE Journal Summer edition discusses a situation in which a high degree of subclass characteristics were found in two firearms during routine casework. Gene Rivera of the Charlotte-Mecklenburg Police Department Crime Laboratory describes how these two firearms came to be discovered through the use of NIBIN, and reemphasizes the importance of the firearms examiner's job to be able to recognize and distinguish subclass characteristics when present. It was this striking case that prompted further research into the propensity and persistence of subclass characteristics in the Sigma Series line, and the potential for individuality to be established on these firearms.

Toolmark Identification

King, E., "Validation Study of Computer Numerical Control (CNC) Consecutively Manufactured Screwdrivers", AFTE Journal, Volume 47(3), Summer 2015, pp. 171-176.

The purpose of this research was to perform a validation study to determine if screwdrivers that are consecutively manufactured using the computer numerical control (CNC) process can be identified by trained forensic examiners after having their class characteristics reproduced by striated toolmark samples. The results were based on participation from seven members of the Scientific Working Group for Firearms and Toolmarks (SWGGUN) and yielded an error rate of 0.00%. This result provides support of toolmark identification in the scientific community, thus complying with the Daubert standard. These results further demonstrate the CNC-consecutively manufacturing process did not eliminate the individual or class characteristics of the screwdrivers and does not interfere with the ability of examiners to correctly associate tools with the marks they leave on surfaces.

Ekstrand, et al, "Virtual Tool Mark Generation for Efficient Striation Analysis", Journal of Forensic Sciences, Volume 59(4), 2014, pp. 950-959.

This is a follow-up study on Zhang and Chumbley's research regarding the development of virtual toolmarks by a 3-D computer simulation that would allow for the development of highly predictable toolmark characterizations. Initial study involved the production of test toolmarks by six screwdriver tips that were then compared by a previously developed statistical algorithm. Preliminary experimental results indicate that the use of a manipulative, virtual tool

could provide quantitative data for the characterization of tool marked surfaces that would improve the scientific basis of toolmark identification. These results support the present theory and conclusions held in Toolmark Identification.

Zheng, X.A., et al, "2D and 3D Topography Comparisons of Toolmarks Produced from Consecutively Manufactured Chisels and Punches", AFTE Journal, Vol. 46(2), Spring 2014, pp. 143-147.

This paper described an automated blind study of toolmarks from consecutively made chisel and punches utilizing 2D and 3D topography analysis. These analytical comparative results were expressed as a maximum value of the normalized Cross Correlation Function (CCF). Based on the CCF metric, all of the toolmarks were correctly identified to the tool that produced them. This study provides additional objective scientific support for the validity of Toolmark Identification.

Chumbley, S. and Morris, M., "Significance of Association in Tool Mark Characteristics", Department of Justice (DOJ) Grant 2009-DN-R-119, Document 243319, August 2013 (Ames Laboratory)

In a recent study of tool marks produced by sequentially made screwdriver tips, the authors developed a computer algorithm that would reliably separate matching tool marks from those that do not match using an analysis based on Mann-Whitney U-statistics applied to data files containing 2-dimensional information obtained using an optical profilometer. These successful results indicate that the significance of association can be accomplished by statistical evaluation of the data file. The work carried out in the present project (and discussed in the report) built upon this success by providing additional statistical information that will increase the relevance of the measurements obtained.

Grieve, T., "Objective Analysis of Toolmarks in Forensics", Graduate Thesis and Dissertations, Paper 13014, 2013, Iowa State University

Since the 1993 court case of *Daubert v. Merrell Dow Pharmaceuticals, Inc.* the subjective nature of toolmark comparison has been questioned by attorneys and law enforcement agencies alike. This has led to an increased drive to establish objective techniques with known error rates, much like the DNA analysis is able to provide. This push has created research in which the 3-D surface profile of two different marks are characterized and the marks' cross sections are run through a comparative statistical algorithm to acquire a value that is intended to indicate the likelihood of a match between the marks. The aforementioned algorithm has been developed and extensively tested through comparison of evenly striated marks made by screwdrivers. However, this algorithm has yet to be applied to quasi-striated marks such as those made by the shear edge of slip-joint pliers. The results of this algorithm's application to the surface will be presented.

Objective mark comparison also extends to comparison of toolmarks made by firearms. In an effort to create objective comparisons, microstamping of firing pins and breech faces have been introduced. The process involves placing unique alphanumeric identifiers surrounded by a radial

code on the surface of the firing pins, which transfer to the cartridge's primer upon firing. Three different guns equipped with micro stamped firing pins were used to fire 3000 cartridges. These cartridges are evaluated based on the clarity of their alphanumeric transfers and the clarity of the radial code surrounding the alphanumerics.

Petraco, N., et al, "Estimation of Striation Pattern Identification Error Rates by Algorithmic Methods", AFTE Journal, Volume 45(3), Summer 2013, pp. 235-244.

This was a computational study using algorithmic methods of toolmark striation patterns produced by screwdriver tips and firearm firing pin apertures in determining error rates. Multivariate analysis, as well as support vector machine methodology, was used to objectively associate these toolmarks with the tools that produced them. Estimated toolmark identification error rates were approximately 1% using these algorithmic methods. The findings of this objective and quantitative scientific research support the general conclusions codified in the AFTE Theory of Identification.

Petraco, N., et al, "Application of Machine Learning to Toolmarks: Statistically Based Methods for Impression Pattern Comparisons", NIJ/NCJRS Document #239048, Award #2009-DN-BX-K041, July 2012

This was a statistical study using 3D quantitative surface topographies of toolmarks, consisting of fired cartridge cases, screwdriver and chisel striations, by confocal microscopy. Principal component and canonical variate analysis, as well as support vector machine methodology, was used to objectively associate these toolmarks with the tools that produced them. Estimated toolmark identification error rates were approximately 1% using these algorithmic methods. The findings of this objective and quantitative scientific research support the general conclusions codified in the AFTE Theory of Identification.

Chumbley, L. S., et al, "Validation of Tool Mark Comparisons Obtained Using a Quantitative, Comparative, Statistical Algorithm", Journal of Forensic Sciences, Volume 55(4), 2010, pp. 953-961.

A statistical analysis and computational algorithm for comparing pairs of toolmarks by profilometry data was conducted. Toolmarks produced by 50 sequentially made screwdrivers, at selected fixed angles, were analyzed both empirically by practicing examiners and by the established computational algorithms. The results of these comparisons, as well as a subsequent blind study with the practicing examiners, showed scores of good agreement between the algorithm and human experts. It was also noted that in some of the examination phases, examiner performance was much better than the algorithm.

Bachrach B., Jain A., Jung S., Koons R.D., "A Statistical Validation of the Individuality and Repeatability of Striated Tool Marks: Screwdrivers and Tongue and Groove Pliers", Journal of Forensic Sciences, Volume 55(2), 2010, pp. 348-357.

This study statistically validated the original premise of individuality in Toolmark Identification by analyzing statistical distributions of similar values resulting from the comparison of Known Matches (KM) and Known Non-Matched (KNM) pairs of striated toolmarks. This quantifiable analysis of KM and KNM toolmark similarity distributions showed nearly error-free identifications.

Firearm and Toolmark Identification Theoretical

Kerkhoff, W., et al, "The Likelihood Ratio Approach in Cartridge Case and Bullet Identification", AFTE Journal, Volume 45(3), Summer 2013, pp. 284-289.

This article summarizes the different aspects of the discussion that led to the implementation of the likelihood ratio approach of firearms identification by the Firearms Section of the Netherlands Forensic Institute (NFI). The authors' (three firearms examiners and a statistician) perspectives on the use of this approach in cartridge case and bullet comparison are shared.

Heikkinen, V., et al, "Quantitative High-Resolution 3D Microscopy Improves Confidence When Determining the Order of Creation of Toolmarks", AFTE Journal, Volume 45(2), Spring 2013, pp. 150-159.

The authors of this paper address the problem of determining the order of creation of engravures (toolmarks) on spent cartridges and fired bullets. We employ quantitative high resolution large area 3D optical imaging for traceable comparison. This solution is novel in the sense that so far only qualitative 2D imaging has been used to address this issue. Our main result is that we can now determine the order of creation of two different kinds of toolmarks on spent cartridges. The main impact of the result is that this technique improves the investigator's confidence when determining the order of creation of the marks as well as the direction of the engravure. Our work advances the state of the art in the field of forensic toolmark inspection by enabling a new quantitatively measured dimension (2D->3D) to improve the objectivity of the forensic analysis. Our work was carried out on copper that was scratched with a steel stylus in a controlled manner. The method was validated using spent cartridges. In practice this effort could aid inspection work aiming at telling apart marks created by the cartridge manufacturer from those made by the gun that fired the cartridge.

Bolton-King, R., et al., "Numerical Classification of Curvilinear Structures for the Identification of Pistol Barrels", Forensic Science International, Issue 220, 2012, pp. 197-209.

This paper demonstrates a numerical pattern recognition method applied to curvilinear image structures. These structures are extracted from physical cross-sections of cast internal pistol barrel surfaces. Variations in structure arise from gun design and manufacturing methods providing a basis for discriminations and identification. Binarised curvilinear land transition images are processed with fast Fourier transform on which principal component analysis is performed. The proposed methodology is therefore a promising novel approach for the classification and identification of firearms.

Petraco, D. K., et al, "Addressing the National Academy of Sciences' Challenge: A Method for Statistical Pattern Comparison of Striated Tool Marks", Journal of Forensic Sciences, Volume 57(4), 2012, pp. 900-911.

Toolmark test specimens from nine slotted screwdrivers were encoded into high-dimensional feature vectors and analyzed by multiple statistical pattern recognition methods. The statistical methods used which are widely known and accepted in academic applications, rely on few assumptions of the data's underlying distribution, can be accompanied by standard confidence levels and are falsifiable. Correct classification rates of at least 97% were achieved.

Fracture Matching

Claytor, D., "Validation of Fracture Matching Through the Microscopic Examination of the Fractured Surfaces of Hacksaw Blades", AFTE Journal, Vol. 42(4), Fall 2010, pp. 323-334.

Validation of fracture matching method utilizing two consecutively manufactured hacksaw blades fractured eleven times and inter-compared. Two hundred fifty-three topical comparisons were conducted between forty-four fractured edges. Additional fractured hacksaw blade test specimens were produced and sent to examiners around the world yielding three hundred-thirty test results.

Weimar, B., et al., "Physical Match Examination of the Joint Faces of Adhesive PVC-Tapes", AFTE Journal, Volume 42(3), Summer 2010, pp. 271-277.

A new method is presented for the physical match examination of the joint faces of cut and torn PVC insulation tapes. The combination of heat treatment, casting and comparison-light-microscopy with oblique light from opposite directions lead to results with a high conclusiveness. The method can be applied with the standard equipment in forensic toolmark laboratories

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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.

Q2 Part 1: *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?*

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. 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.

The following are literature citations, all published within the last five years, for some of the emerging research which has been performed. A short summary follows each citation.

Lilien, R. et al, "Applied Research and Development of a Three-Dimensional Topography System for Imaging and Analysis of Striated and Impressed Tool Marks for Firearm Identification using GelSight" Department of Justice Award 2013-R2-CX-K005, Document 248962, 2015

In the described work, we investigated and developed a novel, accurate, and low-cost system for structural 3D imaging and comparison of cartridge cases. We demonstrated the system's potential for increasing the quality and reducing the cost of forensic analyses. Several recent studies have called for improved imaging technology and matching algorithms to support firearm identification. Our project, named Top-Match, combines the recently developed GelSight high-resolution surface topography imaging system with state-of-the-art algorithms for matching structural features. Compared to competing technologies, our GelSight based system is fast, inexpensive, and not sensitive to the optical properties of the material being measured. This project aims to extend the system to measure and compare striated toolmarks (e.g., aperture shear), to integrate these marks into the scoring function, and to investigate matching algorithms for comparing 3D surface topographies captured using different imaging modalities (e.g. GelSight vs. confocal microscopy). The research work was completed by Cadre Research Labs, a scientific computing contract research organization, working in collaboration with GelSight Inc., a company formed by the MIT researchers who developed the GelSight surface topography imaging technology. The two companies collaborate closely with Todd Weller, a firearms identification specialist and Criminalist in the Oakland Police Department. We also worked with colleagues at NIST and at the International Forensic Science Laboratory & Training Centre in Indianapolis (Dr. James Hamby). We continue to work with Andy Smith (San Francisco PD), Chris Coleman (Contra Costa County Office of the Sheriff), and Karl Larsen (U. Illinois at Chicago). These collaborators continue to be excellent partners and provide both scans and constructive feedback. The results described below made use of a large set of new and previously collected test fires.

McClarin, D., "Adding an Objective Component to Routine Casework: Use of Confocal Microscopy for the Analysis of 9mm Caliber Bullets", AFTE Journal, Volume 47(3), Summer 2015, pp. 161-170.

The Alabama Department of Forensic Sciences (ADFS) procured a confocal microscope for the purpose of incorporating three-dimensional (3D) topographical analysis into routine casework. The purpose of employing such a technique was to assist the firearm and toolmark examiner by

complementing routine analysis with an independent objective analysis. This article covered the research procedures conducted using confocal microscopy at the ADFS.

Spotts, R., et al., "Angular Determination of Toolmarks Using a Computer-Generated Virtual Tool". Journal of Forensic Sciences, Volume 60(4), 2015, pp. 878-893.

A blind study to determine whether virtual toolmarks created using a computer could be used to identify and characterize angle of incidence of physical toolmarks was conducted. Six sequentially manufactured tips and one random screwdriver were used to create toolmarks at different angles. An apparatus controlled tool angle. Resultant toolmarks were randomly coded and sent to the researchers who scanned both tips and toolmarks using an optical profilometer to obtain 3D topography data. Developed software was used to create virtual marks based on the tool topography data. Virtual marks generated at angles from 30 to 85 degrees (5 degree increments) were compared to physical toolmarks using a statistical algorithm. Twenty of twenty toolmarks were correctly identified by the algorithm. On average the algorithm estimated the correct angle of incidence by -6.12 degrees. This study presents the results, their significance, and offers reasons for the average misidentifications.

Spotts, R., and Chumbley, S., "Objective Analysis of Impressed Chisel Toolmarks", Journal of Forensic Sciences, Volume 60(6), 2015, pp. 1436-1440.

Historical and recent challenges to the practice of forensic examination have created a driving force for the formation of objective methods for toolmark identification. In this study, fifty sequentially manufactured chisels were used to create impression toolmarks in lead (500 toolmarks total). An algorithm previously used to statistically separate known matching and nonmatching striated screwdriver marks and quasi-striated plier marks was used to evaluate the chisel marks. Impression evidence, a more complex form of toolmark, poses a more difficult test for the algorithm that was originally designed for striated toolmarks. Results show in this instance that the algorithm can separate matching and nonmatching impression marks, providing further validation of the assumption that toolmarks are identifiably unique.

Riva, F. and Champod, C., "Automatic Comparison and Evaluation of Impressions Left by a Firearm on Fired Cartridge Cases", Journal of Forensic Sciences, Vol. 59(3), May 2014, pp. 637-647.

This paper reported on an automated study of marks contained on fired cartridge cases from seventy-nine (79) 9mm Luger caliber pistols were conducted using 3D surface topography analysis and coupled to a bivariate evaluative model to assign likelihood ratios. The purpose of this analytic system was to conduct an objective comparative analysis with a robust statistical evaluation basis to the results. The system reflected a very high discriminating ability between the known and non-known specimens. This study also reflected very low rates of misleading evidence depending on the firearm considered.

Yammen, S., and Muneesawang, P., "Cartridge Case Image Matching using Effective Correlation Area Based Method", Forensic Science International, Issue 229, 2013, pp. 27-42.

A firearm leaves a unique impression on fired cartridge cases. The cross-correlation function plays an important role in matching the characteristic features on the cartridge case found at the crime scene with a specific firearm, for accurate firearm identification. This paper proposes that the computational forensic techniques of alignment and effective correlation area-based approaches to image matching are essential to firearm identification. Specifically, the reference and the corresponding cartridge cases are aligned according to the phase-correlation criterion on the transform domain. The informative segments of the breech face marks are identified by a cross-covariance coefficient using the coefficient value in a window located locally in the image space. The segments are then passed to the measurement of edge density for computing effective correlation areas. Experimental results on a new dataset show that the correlation system can make use of the best properties of alignment and effective correlation area-based approaches, and can attain significant improvement of image-correlation results, compared with the traditional image-matching methods for firearm identification, which employ cartridge-case samples. An analysis of image-alignment score matrices suggests that all translation and scaling parameters are estimated correctly, and contribute to the successful extraction of effective correlation areas. It was found that the proposed method has a high discriminant power, compared with the conventional correlator. This paper advocates that this method will enable forensic science to compile a large-scale image database to perform correlation of cartridge case bases, in order to identify firearms that involve pairwise alignments and comparisons.

Zhang, S. and Chumbley, L.S., "Manipulative Virtual Tools for Tool Mark Characterization", NCJRS Document #241443, Award # 2009-DN-R-119, March 2013.

This paper describes research on the development of virtual toolmarks by a 3-D computer simulation that would allow for the development of highly predictable toolmark characterizations. Initial study involved the production of test toolmarks by six screwdriver tips that were then compared by a previously developed statistical algorithm.

Preliminary experimental results indicated that the use of a manipulative, virtual tool could provide quantitative data for the characterization of tool marked surfaces that would improve the scientific basis of toolmark identification.

Song, J., et al., "Development of Ballistics Identification- from Image Comparison to Topography Measurement in Surface Metrology", Measurement Science and Technology, Volume 23, Number 054010, March, 2012.

This was a systematic study of direct measurement and correlation of surface topography on fired bullet markings. Based on this on this system, a prototype for bullet signature measurement and correlation was developed that has demonstrated superior correlation results for bullet signature identifications.

Chu, W., et al., "Selecting Valid Correlation Areas for Automated Bullet Identification System Based on Striation Detection", Journal of Research of the National Institute of Standards and Technology, Volume 116, Number 3, May-June 2011.

This paper detailed a study on fired bullet markings using automated bullet identification systems that employ an edge detection algorithm and selection process that locates the edge points of significant toolmark features was conducted. Results of this study validated the differentiation ability of individual characteristics if a proper striation threshold length could be established.

Weavers, G., et al, "A Comprehensive Statistical Analysis of Striated Tool Mark Examinations, Part 2: Comparing Known Matches and Known Non- Matches using Likelihood Ratios", AFTE Journal, Volume 43(2), Spring 2011, pp. 137-145.

A potential model for increasing the objectivity in the interpretation of toolmarks is explored using consecutively matching striae (CMS) and Bayesian inference. Given the nature of the data, standard statistical thinking suggests that Bayesian inference is likely to be the most powerful method of interpretation. The unavoidable paucity of data for high CMS runs for the known non-match condition is handled using a small advance in modelling. The resulting likelihood ratios show some, but incomplete separation between the known match and known non-match conditions. Although promising, the resulting incomplete separation between known match and known non-match is thought to represent limitations of the CMS summary of the complete pattern and limitations of the modelling used.

Baldwin, et al, "Statistical Tools for Forensic Analysis of Toolmarks", Ames Laboratory, Iowa State University, Report IS-5160, 2011

Recovery and comparison of toolmarks, footprint impressions, and fractured surfaces connected to a crime scene are of great importance in forensic science. The purpose of this project is to provide statistical tools for the validation of the proposition that particular manufacturing processes produce marks on the work-product (or tool) that are substantially different from tool to tool. The approach to validation involves the collection of digital images of toolmarks produced by various tool manufacturing methods on produced work-products and the development of statistical methods for data reduction and analysis of the images. The developed statistical methods provide **a** means to objectively calculate a "degree of association" between matches of similarity produced toolmarks. The basis for statistical method development relies on "discriminating criteria" that examiners use to identify features and spatial relationships in their analysis of forensic samples. The developed data reduction algorithms utilize the same rules used by examiners for classification and association of toolmarks.

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

Q3: *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?*

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.

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 here in its entirety.

Attachment (Click on icon to open document):

Q4: 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.

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".

Attachment (Click on icon to open document):

Q5: What standards of validity and reliability should new forensic methods be required to meet before they are introduced in court?

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 can<u>not</u> 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.

FIGURE 1:
CARTRIDGE CASE COMPARISON

FIGURE 2:
BULLET COMPARISON

Note the dark, soot-stained surface of these two bullets when viewed and photographed under the optical comparison microscope. This dark material presents no problem for the digital imaging system employed here. Moreover, a much better comparison appears in the digital image on the right.

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.

Q7: Please share any additional comments.

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.

Attachment (Click on icon to open document):