



*The following statement regarding the science involved in the discipline of forensic toolmark examinations and conclusions is the opinion of the Scientific Working Group for Firearms and Toolmarks (SWGGUN). The SWGGUN is a professional association of international scientific experts in the forensic science discipline of Toolmark Identification with the mission of providing a consensus of guidelines, studies, and other findings of interest to the forensic community.*

## **The Foundations of Firearm and Toolmark Identification**

**Abstract:** In 2005, the SWGGUN formed a Science Committee that was tasked to conduct a comprehensive review of all pertinent and related documents in the toolmark identification discipline in order to determine the reliability of their conclusions in judicial proceedings. During the course of this review, the SWGGUN Science Committee also examined the scientific rudiments upon which this discipline is based. The purpose of this study was to chronicle the origins and evolution of the discipline of firearm and toolmark identification as a science.

### **SCIENTIFIC RUDIMENTS**

Regardless of the branch of knowledge being investigated, science always involves systematic procedures to gather reliable and testable knowledge. Depending on the specific realm of scientific inquiry, a variety of procedures may be used. Therefore, it is important to establish the context for the discussion by developing a common understanding of the procedures underlying the discovery, origination and development of firearm and toolmark identification as a science.

In this report, the Committee relied on Richard Feynman's writings [1] on the character of physical laws for guidance in articulating the critical scientific method elements used in the discovery, origination, and evolution of firearm and toolmark identification. Feynman describes these principles and empirical processes of discovery and/or demonstrated characteristics necessary for scientific investigation as 1) observation of phenomena, 2) formation of a hypothesis concerning the observed phenomena 3) experimentation to demonstrate truth or falseness of the hypothesis, and 4) a conclusion that validates or modifies the hypothesis into a supported theory.

The following scientific method elements consistent to those rudiments described by Feynman have been used in establishing the forensic discipline of firearm and toolmark identification as a

science: 1) observation of a phenomenon, 2) developing a premise, forming a hypothesis, 3) develop a testing model, 4) using reliable methodology, and 5) forming a theory. The application of these elements in the origination and development of the forensic discipline of firearm and toolmark identification are delineated below.

**PHENOMENON** - The first documentation noting the observation of toolmarks was published in the *Buffalo Medical Journal* in 1905. Concurrent with this were observations being made by scientists in the United States, Germany, and France.

**PREMISE** - Tools have and impart distinctive features that can distinguish, or be traced back to, that particular tool. This is referred to as the Premise of Uniqueness by Dr. Paul Kirk [2].

**HYPOTHESIS** - Tools have distinctive features, called individual characteristics, which are random in nature. These individual characteristics enable a properly trained and competent examiner to trace a toolmark back to the tool that produced it with great accuracy.

**TESTING MODEL** - The testing model used for over 50 years is the study of toolmarks produced from consecutively manufactured tools where there would be the highest possibility of toolmark carryover (e.g., two tools possessing and imparting indistinguishable toolmarks).

**METHODOLOGY** - Side-by-side comparison that allows analysis of questioned toolmark features to known source toolmark features in a direct (one-to-one) spatial relationship to each other. This is commonly referred to pattern recognition and was adapted from the textile industry.

**THEORY** - A conclusion of common origin, between two compared toolmarks, can be made when there is sufficient correspondence of distinctive and individual features. A properly trained and competent examiner can trace a toolmark back to the tool that produced it with great accuracy.

### **Foundational Overview of Firearm and Toolmark Identification as a Science**

Toolmark Identification is a forensic science discipline that is typically referred to as Firearm and Toolmark Identification because a firearm is considered a specialized tool and the most common tool examined by forensic science laboratories. Congruous with the elements of scientific inquiry as described under Scientific Rudiments, toolmark identification is derived from previously established scientific principles from recognized disciplines of physical science to explain certain observed phenomena. And, as such, is considered an applied science rather than a pure or basic science.

The basis for identification in firearm and toolmark identification is founded on the principle of uniqueness as described by Kirk [2] through Tuthill [3]; wherein, all objects are unique to themselves and thus can be differentiated from one another. With respect to tools and toolmarks, when the surface of a harder object (the tool) comes into contact with a softer object (the work piece), the harder object will impart its unique marks or features on the softer object thereby enabling a trained examiner to identify the source of a toolmark by comparing known toolmarks produced by that tool. In firearm and toolmark identification it is important to understand not only the practical elements of performing a comparison but also how tools are manufactured and the mechanics by which toolmarks are made.

The mechanism for the origination of toolmarks is founded on well-established principles derived from the physical sciences that include physics, metallurgy, metallography, and materials science, as well as many mechanical properties presently used in mechanical and industrial engineering. The working edge(s) of tools (those surfaces that come into contact with the work piece and responsible for leaving toolmarks) are manufactured by a number of machining methods. Most manufacturing processes involve the transfer of rapidly changing or random marks onto work pieces such as barrel bores, breechfaces, firing pins, screwdriver blades, and the working surfaces of other common tools. This is caused principally by the phenomena of tool wear and chip formation or by electrical/chemical erosion. Microscopic marks on tools may then continue to change from further wear or abuse. These irregularities are considered unique and capable of being used to individualize or distinguish one tool from another.

When the working edges of these tools come into contact with a work piece, these random irregularities may be transferred to the work piece in the form of a toolmark. A comparative examination of toolmarks may then permit a trained examiner to determine whether the toolmarks share a common source. The comparative examination process used in firearm and toolmark identification is similar to those used in the other comparative disciplines in forensic science. This process begins with a study of the most general characteristics (class) of items to be compared, progressing through (subclass, if present) to the analysis and comparison to the most specific characteristics (individual). The most widely accepted method used in conducting such an examination is a side-by-side microscopic comparison of the markings on a questioned material item to known source marks imparted by a tool.

A number of studies have been published that examine various manufacturing methods and the uniqueness of marks produced on the tool working surfaces. Of these, some of the most valuable are those that have examined consecutively manufactured tools. The reason is that if any tool working surfaces should appear most similar and difficult to distinguish from one

another, it would be those that were manufactured consecutively [4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16]. These studies have demonstrated that sufficient uniqueness is produced on tool working surfaces such that toolmarks produced by these tool working surfaces could be correctly associated to the tool that produced the toolmark.

Years of empirical and experimental testing has allowed for the formation of a standard by which trained examiners can form an opinion of common source when performing a comparative examination. This testing includes the aforementioned studies of consecutively manufactured tools, as well as, comparing the theoretical and demonstrated probabilities of finding patterns of striae within a toolmark. Several experiments comparing the number of matching striae or patterns of striae within toolmarks using a statistical approach have been documented [17,18,19,20,21].

The most recent, although certainly not new, area of research involves machine-based analyses of toolmarked surfaces. To date, the focus of this research has involved computerized systems that analyze the similarity of surfaces marked by the same tool and those marked by different tools [22, 23, 24, 25, 26, 27, 28]. The results of these experiments have shown conclusively that a machine can detect significant differences between known matches and known non-matches [29].

These empirical and experimental studies, based on the fundamental proposition that different tool working surfaces will display sufficient uniqueness to permit the identification of a toolmark produced by a tool to the correct source, have allowed for the formation and continued testing of the Association of Firearm and Tool Mark Examiners (AFTE) Theory of Identification. “The Theory of Identification as it pertains to the comparison of toolmarks enables opinions of common origin to be made when unique surface contours of two toolmarks are in ‘sufficient agreement’. 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 the agreement demonstrated by toolmarks known to have been produced by the same tool.”[30] Derived from principles in established physical science disciplines, the theories and hypothetical propositions described were formed and tested to validate or falsify the science of firearm and toolmark identification. Through on-going model testing, the AFTE Theory of Identification has been continually validated and to date has never been disproven.

Any individual association or identification conclusion effected through this examination process is based not on absolute certainty, but rather on the practical certainty of the underlying (validated) scientific theory. The significance of identifications in this context can be

evaluated in one of two ways. These include statistics to aid in the development of random match probabilities and validation testing of trained examiners.

Studies that have assessed statistical approaches and probabilities have demonstrated that toolmark identifications are reliable. However, using such an approach is not practical in casework and has significant limitations. Probabilities do not describe cause and effect relationships, but rather demonstrate the chances of a particular event happening in general based on observations of a limited population. While statistics can lend an order to the estimation of uncertainty, its utility for a particular case is limited in that aspect. In addition, mathematical methods require some form of quantification of observed individual random markings. Such quantification has been modeled and, for striated toolmarks, has achieved some level of codification [17, 31, 32, 33, 34, 35]. While continuing study is taking place for both mechanical and computerized models for quantification, such methods are not routinely used in casework.

The other manner in which meaning can be placed on the significance of an identification is through validation testing and assessment of error rates. In such testing, a trained examiner is challenged with the comparative examination of toolmarks in an attempt to determine whether the toolmarks share a common source. Due to the nature of the examination, a subjective interpretation of observations made during the examination process of these validation studies can provide for a reliable estimate of how often, using accepted procedures and methods, a trained examiner will make an error in the determination of common source [36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46]. All of these studies help to demonstrate the validity of firearm and toolmark identification and show that despite the subjective nature of the analysis, competent examiners will rarely, if ever, commit false identifications or false eliminations.

Given the endless variety of tools and firearms and the occasional development of new manufacturing methods, this effort, in principle, could be expanded considerably. Having an entity outside the forensic laboratory prepare and administer each test could maximize objectivity, allow for testing in multiple laboratories, and minimize the workload on laboratory examiners. In addition to providing useful information about errors, validity-test results can be used to evaluate current identification and elimination standards, while helping to identify possible obstacles in the field such as the discovery of significant subclass marks produced by a specific make and model tool.

### **Toolmark Identification is a Forensic Science**

The science of firearm and toolmark identification is an applied science most often utilized for forensic purposes to aid the criminal justice system for presentation to a court of law. Over the

course of time, many sciences have been developed for answering questions disputed in adversarial judicial systems around the world. To guard against the possibility of fraudulent testimony, several courts have developed criteria for the acceptance or rejection of the presentation of expert testimony. That standard of acceptance has varied and evolved over the years and relies greatly on judges (with or without a scientific background) to make the final decision as to the relevance and reliability of the testimony in question. To date, firearm and toolmark identification has stood the test of judicial scrutiny and has served communities around the world in solving crime.

## **CONCLUSION**

During this study the Science Committee found that Firearm and Toolmark Identification:

- Originated and evolved into an applied scientific discipline following the general precepts of scientific inquiry.
- Was founded on a sound scientific method that applied a logical premise to explain noted phenomena.
- From this premise, a hypothesis, as well as, testing model and methodology were developed.
- The underlying theory and methodology is continually tested (by scientists in and out of discipline) and validated.

Based on the information provided above that summarizes sound foundational principles, logical basis of identification, methodologies, established protocols and practices long-accepted, it is the conclusion of the Scientific Working Group for Firearms and Toolmarks (SWGGUN) that the discipline of Firearms/Toolmark Identification is scientific and reliable. Concomitantly, the identifications, individual associations or “matches” effected in this discipline have firm scientific grounding with an extremely high degree of reliability based on the practical certainty of the validated theory.

The SWGGUN concludes that sufficient validation testing by competent examiners and collaborating scientists have been conducted to affirm the theory of firearm and toolmark identification over the past ninety years for it to be considered a legitimate science pursuant to the criteria set forth in the scientific method. At the same time, the SWGGUN also is cognizant of the need for continual testing of the underlying theory, the scrutiny of the employed methods and procedures, along with the continual awareness of emerging technologies that could be used to further these endeavors.

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- <sup>2</sup> Kirk, P. *The Ontogeny of Criminalistics*. *The Journal of Criminal Law, Criminology and Police Science*, 54(2): 236.
- <sup>3</sup> Tuthill, H. *Individualization: Principles and Procedures in Criminalistics*. Lightning Powder Co., Salem, OR, 1994.
- <sup>4</sup> Churchman, J.A. *The Reproduction of Characteristics in Signatures of Cooey Rifles*. *RCMP Police Gazette* 11(5): 46-56.
- <sup>5</sup> Murdock, J. *A General Discussion of Gun Barrel Individuality and an Empirical Assessment of the Individuality of Consecutively Button Rifled .22 Caliber Rifle Barrels*. *AFTE Journal* 13(3): 84-95.
- <sup>6</sup> Matty, W. *A Comparison of Three Individual Barrels Produced from One Button Rifled Barrel Blank*. *AFTE* 17(3): 64-69.
- <sup>7</sup> Brundage, D. *The Identification of Consecutively Rifled Gun Barrels*. *AFTE Journal* 30(3): 438-444.
- <sup>8</sup> Tulleners, F. and Hamiel, J. *Sub Class Characteristics of Sequentially Rifled 38 Special S&W Revolver Barrels*. *AFTE Journal* 31(2): 117-122.
- <sup>9</sup> Lopez, L. and Grew, S. *Consecutively Machined Ruger Bolt Faces*. *AFTE* 32(1): 19-24.
- <sup>10</sup> Coffman, B. *Computer Numerical Control (CNC) Production Tooling and Repeatable Characteristics on Ten RemingtonModel 870 Production Run Breech Bolts*. *AFTE* 35(1): 49-54.
- <sup>11</sup> Nichols, R. *Firearm and Tool Mark Identification: The Scientific Reliability and Validity of the AFTE Theory of Identification Discussed Within the Framework of a Study of Ten Consecutively Manufactured Extractors*. *AFTE Journal* 36(1): 67-88.
- <sup>12</sup> Lightstone, L. *The Potential for and Persistence of Subclass Characteristics on the Breech Faces of SW40VE Smith &Wesson Sigma Pistols*. *AFTE* 42(4): 308-322.
- <sup>13</sup> Butcher, S. and Pugh, P. *A Study of Marks Made by Bolt Cutters*. *Journal of the Forensic Science Society* 15: 115-126.
- <sup>14</sup> Cassidy, F.H. *Examination of Toolmarks from Sequentially Manufactured Tongue-and-Groove Pliers*. *Journal of Forensic Science* 25(4): 796-809.
- <sup>15</sup> Eckerman, S. *A Study of Consecutively Manufactured Chisels*. *AFTE Journal* 34(4): 379-390.
- <sup>16</sup> Clow, C. *Cartilage Stabbing with Consecutively Manufactured Knives: A Response to Ramirez v. State of Florida*. *AFTE Journal* 37(2): 86-116.
- <sup>17</sup> Biasotti, A. *A Statistical Study of the Individual Characteristics of Fired Bullets*. *Journal of Forensic Science*, 4(1): 34-50.
- <sup>18</sup> Bracket, J.W. *A Study of Idealized Striated Marks and Their Comparisons Using Models*. *Journal of the Forensic Science Society*, 10(1): 27-56.
- <sup>19</sup> Deinet, W. *Studies of Models of Striated Marks Generated by Random Processes*. *Journal of Forensic Sciences*, 26(1): 35-50.
- <sup>20</sup> Stone, R. *How Unique are Impressed Toolmarks?* *AFTE Journal* 35(4): 376-383.
- <sup>21</sup> Collins, E. *How "Unique" Are Impressed Toolmarks? – An Empirical Study of 20 Worn Hammer Faces*. *AFTE Journal* 37(4): 252-295.

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- <sup>22</sup> Bachrach, B. et al. A Statistical Validation of the Individuality and Repeatability of Striated Tool Marks: Screwdrivers and Tongue and Groove Pliers. *Journal of Forensic Sciences*, 55(2): 348-357. In the abstract, the authors offer that, "An analysis of the resulting matching and nonmatching similarity distributions [of striated toolmark images] shows nearly error-free identification under most conditions. These results provide substantial support for the validity of the premise of tool mark identification."
- <sup>23</sup> Chumbley, L.S. et al. Validation of Tool Mark Comparisons Obtained Using a Quantitative, Comparative, Statistical Algorithm. *Journal of Forensic Sciences* 55(4): 953-961.
- <sup>24</sup> Weller, T. et al. Confocal Microscopy Analysis of Breech Face Marks on Cartridge Cases From 10 Consecutively Manufactured Pistol Slides. *Journal of Forensic Sciences*, 57(4): 912-917.
- <sup>25</sup> Petraco, N., et al. Addressing the National Academy of Sciences' Challenge: A Method for Statistical Pattern Comparison of Striated Tool Marks. *Journal of Forensic Sciences*, 57(4): 900-911.
- <sup>26</sup> Petraco, N., et al. Forensic Surface Metrology: Tool Mark Evidence. *Scanning*, 33:272-278.
- <sup>27</sup> Song, J. et al. Development of Ballistics Identification – From Image Comparison to Topography Measurement in Surface Metrology. *Measurement Science and Technology*, 23.
- <sup>28</sup> Petraco, N. Application of Machine Learning to Toolmarks Statistically Based Methods for Impression Pattern Comparisons. 2012 USDOJ 2009-DN-BX-K041.
- <sup>29</sup> With continued research and development, machines such as these could eventually be used in laboratories for independent confirmations of examiners' conclusions in casework and, ultimately, may replace human judgment in the comparison process. Because the working surfaces of different tools change at unpredictable rates, "ID machines" (or the identification cut-off values inherent to these systems) would need to be fine-tuned to reach acceptable trade-offs among false positives and negatives and sensitivity and specificity. This desired balance will undoubtedly be the subject of some discussion and may require specific research to justify whatever balance is ultimately selected. Clearly, machines will not find wide acceptance unless and until the overall quality of their output can be demonstrated to match or exceed those of human examiners.
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- <sup>36</sup> DeFrance, C. and Van Arsdale, M. Validation Study of Electrochemical Rifling. *AFTE Journal*, 35(1): 35-37.

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