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Assessment of Consecutive Matching Striae

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Assessment of Consecutive Matching Striae

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ABSTRACT

Firearm and tool mark identification relies on criteria that have been accepted in the field to assist firearm examiners in determining if a bullet has been fired from a particular firearm. In this research, criteria for firearm conclusions were reviewed, in light of current challenges by the scientific and legal community concerning the reliability of firearm and tool mark identification theories and practice. The aim of the research is to determine the effectiveness of Consecutive Matching Striae (CMS) criteria with respect to two-dimensional and three-dimensional marks viewed on both known and unknown test bullets from different caliber weapons. This particular research was conducted using .25 Auto, .380 Auto, 38 SPL, 9mm, .40 S&W, .45 Auto, and 7.62×39mm bullets. All data were used to evaluate the validity of CMS for identification purposes by examining groove impressions. The results revealed that current CMS criteria were valid for firearm identification but some known match comparisons were excluded when applying CMS criteria. Therefore, new criteria were proposed for assistance of firearm identification.

Keywords: consecutive matching striae (CMS), identification

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CHAPTER ONE:

INTRODUCTION

Background of the Research

The analysis of bullets fired from a particular firearm is of critical importance in the forensic discipline of firearm and tool mark analysis. The science of ballistics began in the early 1900's when it was first accepted that, as a bullet is fired from a gun, a small group of marks are left on it which can be analyzed and linked to specific firearms (Heard, 2008). However, the identification process has remained subjective mostly, with emphasis regarding the meaning of such unique marks being placed on an examiner's experience.

Originally, firearm and tool mark examiners drew conclusions based on their own knowledge and experience rather than using objective criteria. There were no specifics on how many or what types of similarities between evidence and test samples were required for an identification, or relevant data to support such conclusions. The earliest example of using objective criteria came from a pioneer in the field of forensic ballistics and firearm identification, Calvin Goddard. He published an article titled *Forensic Ballistics* in 1925, where he discussed using the comparison microscope to view the magnified images of two bullets or cartridge cases for identification ("Forensic Firearms and Tool Marks Time Line", n.d.). Even though using microscopes made observation more informative, the interpretation of the results themselves was still very much a subjective process.

In 1959, a further advancement towards more objective criteria occurred when Alfred A. Biasotti suggested that identification should not only be obtained by calculating the percentage of matching striae. He discovered striations created from different firearms can be matched to some extent, but the concept of consecutiveness can exclude this effect and reduce misidentifications. This method has come to be referred to as Consecutive Matching Striae (CMS) which, according to Dillon (n.d.), is "a quantitative method of describing observed pattern matches. CMS is simply a means of articulating the best known non-match described and defined by the AFTE Theory of Identification." Biasotti's contributions revolutionized the field by reducing subjective analysis and improving objectivity. However, concerns over the consistency of methodology have persisted long after his work. Nichols (1997) reviewed 34 firearm identification articles and concluded that "all have had a common concern about the basis upon which the identification of firearms and tool marks is achieved" (p.74).

These concerns about differing uses of CMS are understandable, but can be remedied through more rigorous and objective criteria. The process of firearm mark identification can be used to positively determine if the bullet was fired from a specific gun because all firearms have unique characteristics. This point should not be underestimated; indeed, the premise of firearm and tool mark identification is based on uniqueness. Technology can also play an important role in providing a significant improvement in objective criteria.

The basis of firearm identification is supported by research which concludes that there are no two tools, such as firearms, which could leave the same unique marks on a bullet, even firearms of the same make and model. Use and abuse of tools as well as manufacturing processes leave unique surface characteristics that cannot be reproduced in other tools. Additionally, individual characteristics of firearms and tools may change over time, providing further unique characteristics. Tests have indicated that even after discharging hundreds of rounds through a firearm, individual characteristics of the last fired bullet can still show similarities to the first test fire.

In terms of criminal cases involving firearms, the applications of these techniques and their reliability have great significance. In forensic laboratories, firearm examiners compare marks on bullets or cartridge cases that are collected from crime scenes with test marks produced by firing a particular gun in the laboratory. The object is to determine whether individual characteristics of evidence and test marks are the same or fired from different weapons. Once a conclusion is made, expert witness testimony involving the results may play an important role in court. In order for the expert witness testimony to be admissible, the science governing the analysis must follow strict criteria established by Daubert (Daubert v. Merrell Dow Pharmaceuticals, 1993). There are four aspects of Daubert criteria for evaluating the admissibility of expert testimony: (1) whether the method on which the testimony is based has been conducted by hypothesis testing. (2) the known or potential error rate relating to the method. (3) whether the method has been subjected to peer review and publication. (4) whether the method is generally accepted in the scientific community. Some challenges from legal professionals (Schwartz, 2005) to the use of firearm identification specialists as expert witnesses have been made under Daubert ruling. Current firearm identification methods such as Consecutive Matching Striae (CMS) follow the Daubert standards and support their validity using objective criteria (Nichols, 2007).

Statement of Problem

Recent legal challenges to firearm identifications were expressed by Cantor (2010):

> "In 2008, the National Research Council Committee to Assess the Feasibility, Accuracy, and Technical Capability of a National Ballistics Database provided a report that substantially boosts the defense challenges available to assault an attorney. The committee concluded that there are serious scientific problems in both the underlining premises of firearms and tool mark identification and the methods firearms and tool mark examiners use to make identifications. It's this very shadow of doubt that can be of great use to assault an attorney."

When dealing with the issue of subjectivity and objectivity within the firearm and tool mark identification field, it should be noted that the basic process of identification is to compare both evidence and test marks to each other, observe the surface of striations in relative positions, width and curvature, and then draw a conclusion based on those observations. Since these observations are repeatable, other qualified examiners should be able to make the same observations by utilizing CMS criteria.

CMS has the potential to assist firearm and tool mark identification with determining objective conclusions. “It is a means of describing the pattern that one is observing” (Nichols, 2007). It is true that traditional identification relies on training and experience, so it may appear subjective to a juror or judge as there are no criteria that can be utilized and validated by others. However, when conducting CMS, it is not only based on training and experience, but a number of studies have shown the criteria are reliable in the field. Conclusions based on CMS are intended to be objective and the research proposed here is designed to assess its objectivity.

Purpose of the Research

The purpose of this research was to evaluate CMS criteria by using test fires with different calibers and observing striae on both two dimensional and three dimensional images.

Furthermore, the data were used to provide a guideline in relation to AFTE Theory of Conclusions for firearm examiners in the field of firearm and tool mark analysis.

Limitations

The striations on bullets that have been fired by different guns may vary as test fires with slippage or damage may influence the quality of striae production. Additionally, when determining the consecutiveness and number of matching lines, some confusion may occur between examiners due to their training experience.

CHAPTER TWO:

REVIEW OF THE LITERATURE

In 1926, pursuant to his experience, Goddard stated that “every pistol barrel, even when fresh from the factory contains minute irregularities which are similar to it alone, and which will never be reproduced in any other” (p.97). As mentioned previously, Goddard’s contributions to the field were invaluable and by combining analysis with the use of a comparison microscope, he propelled the forensic identification discipline.

CMS was initially introduced by Biasotti when he revealed that consecutive individual characteristics and multiple occurrences appeared to provide a reliable and practical approach to establish objective criteria of identification in striation matching. In his research he viewed marks on known match and known non-match lead and full metal jacketed bullets being fired from .38 Special revolvers. The data collected included matching lines, total numbers of lines, and frequency of occurrence of consecutive matching lines. The study (1959) indicated “no more than three consecutively matching lines were found for all lead bullets or more than four for metal jacketed bullets from all different gun comparisons” (pp.34-50). He also stated that the percentage of matching lines between evidence and test bullets should not be used for the result of identification. During the experiment, 36% to 38% of matching lines from the same gun have been seen for lead bullets and 21% to 24% for metal-cased bullets. However, 15%-20% matching lines from different guns occurred. Based on the results above, he concluded that "relatively speaking this data indicates that even under such ideal conditions the average percent match for bullets from the same gun is low and the percent match for bullets from different guns is high, which should illustrate the limited value of percent matching lines without regard to consecutiveness" (p.44).

Dougherty's (1969) study on firearm and tool mark identification was one of the earliest articles on the theory of striae matching which "describes a systematic examination of fired projectiles, determination of their class characteristics, [and] the characteristics of projectiles, which then allows them to be identified as to manufacturer by the base and cannelures" (p.453).

Tsuneo Uchiyama (1988a) concluded that the most significant work in firearms was to identify a particular gun to the exclusion of all other guns with the help of evidence bullets that were fired from it. However, there were no explanations to support the conclusions of identity by the examiner. He also suggested that there were two parts of the process in the firearms identification methodology:

1. To examine and compare the class characteristics of evidence bullets and test bullets;
2. To examine and compare the individual characteristics of evidence and test bullets.

Uchiyama also indicated that some characteristics of the bore surface were transferred from a gun to the fired bullets. Even though this would be subjective, it still could be possible to determine those characteristics that were the result of common origin. When counting the striae of the fired bullets, the author indicated that the indented striae might be suitable for jacketed bullets; however, for lead bullets, it was not suitable to count only indented or protruded lines because they might interweave with each other in some cases. Uchiyama used a statistical model to build up criteria for identification of land marks.

Uchiyama (1992) carried on research that used a mathematical model in which both the width and position of the striae were used to figure out the probability of corresponding striae. In this model, “Coincidence Ratio” was introduced as a parameter where width and position were taken into account. When the firearm examiner determined the number of corresponding (matching) striae, a Critical Coincidence Ratio (CCR) could be set. If the coincidence ratio of striae was more than the CCR, both striae were matched. Finally, he concluded that the total number of matched lines or the percent match alone cannot make an identification. In the end of the article, he examined the probability of corresponding striae by using a computer simulation. The computer program generated a relationship with respect to the number of striae per mark, average width of striae, and coefficient variation of striae width. The application of the simulation to actual striated marks was the first step to allow examiners to establish and validate objective comparison criteria to determine common origin.

In 1997, Biasotti and Murdock published "Conservative Quantitative Criteria for Identification". They utilized CMS technology and established specific criteria associated with this identification approach to include two dimensional tool marks and three dimensional tool marks. In this study, data was combined from Biasotti's previous work and new data was incorporated. Two dimensional tool marks are best described as contour variations viewed as flat scale imagery having length and width, and no significant depth; three dimensional tool marks are contour variations viewed with length, width and depth. Biasotti and Murdock further expanded these definitive characteristics through their "Conservative Quantitative Criteria for Identification" as viewed in their research as (1997, pp.124-151):

> "Two dimensional tool marks are those that are present when at least two groups of at least five consecutive matching striae appear in the same relative position, or one group of eight consecutive matching striae are in agreement in an evidence tool mark. Three dimensional tool marks are those present when at least two different groups of at least three consecutive matching striae appear in the same relative position, or one group of six consecutive matching striae are in agreement in an evidence tool mark compared to a test tool mark.

However, for these criteria to apply, the possibility of subclass characteristics must be ruled out."

Miller (2000) found that caliber should not be a factor in applying the Biasotti and Murdock consecutive single group criteria between the known match comparisons and known non-match comparisons. The data for this discussion were collected from the calibers of .25 Auto, .380 Auto, and 9mm. These data were applied to evaluate the consecutive group of striae concept as a criterion for identification, and were compared with the 38 Special data.

As it was addressed in this study, the consecutive group criteria needed for identification were one group of eight consecutive matching striae or at least two groups of five. For instance, in known non-match comparisons, no single group beyond four consecutive matching striae was obtained for .380 ACP bullets. With this criterion, no false identification would occur in known non-match land impression comparisons. In addition, there were many differences existing in the comparisons between the single group of eight consecutive striae and the single group of six consecutive striae. Different tool marks would be able to meet these criteria. For instance, only 2% of the eight consecutive striae met the criteria of .25 Auto, whereas none of the six consecutive striae met this requirement. In the Miller's (2000) research, it can be concluded that further work is required in the criterion for tool mark identification. Although the criteria obtained in consecutive groups are available for examiners to make an identification, they also exclude some correct identifications.

In another of Miller's (2001) articles, pairs of test fired bullets from ten consecutively manufactured rifle barrels were obtained to examine the influence of subclass characteristics. It has been demonstrated that the best possibility of the reproduction of subclass characteristics between fired bullets is likely to happen from barrels rifled consecutively. The main reason is that less change has taken place on a tools' working surface in a short duration than in a longer one. This study was aimed at determining whether bullets could be identified to a specific barrel. In the bullets fired from different barrels of similar tool marks, it is necessary to ascertain which one could be attributed to subclass characteristics between the barrels, and the propriety of the expected conservative criteria for identification. Miller (2001) indicated that even though some subclass influence might take place on consecutively manufactured rifle barrels, they would never affect the correct identification of the bullets. It is a difficult task to find areas that were produced by a subclass source.

Schwartz (2005) challenged several areas of firearm and tool mark identifications (pp. 6-11):

- Individual characteristics are comprised of non-unique marks
- Subclass characteristics may be confused with individual characteristics

- Individual marks of a particular tool change over time

She described the traditional approach of firearms identification as being “subjective” and stated that the CMS approach is “objective.” However, she fails to acknowledge the work of Miller, who conducted numerous examinations on tool marks of varying widths and did not find that using the conservative CMS criteria for identification to result in a false inclusion. This research assesses CMS as a more objective approach of performing microscopic comparisons because it is a way to document consecutive matching lines that the firearm examiner is observing in striated tool marks.

CHAPTER THREE:

RESEARCH METHODOLOGY

Two objectives were outlined by this research. The first objective was to determine the reliability of CMS criteria by recording the groups of consecutive matching striae which occurred by chance on both two dimensional and three dimensional tool marks of test fires. Ten pairs of firearms of same make and similar model for a total of twenty guns were chosen for examination. For each pair of guns, twenty known-match bullets were obtained (labeled #1- #10 and #1a- #10a); therefore 200 fired bullets were recovered in total. Next, each bullet was microscopically examined side-by-side with all the other bullets and compared in order to evaluate striations produced by barrels, and the known match comparisons and best known non-match comparisons were also photographed for further analysis (using 28X magnification of the microscope).

In this research, 1,200 groove impression comparisons were conducted for known match bullets, as well as 1,500 groove impression comparisons for known non-match bullets. The ten best known match comparisons and ten best known non-match comparisons with the highest number of consecutive matching groups were recorded. These groups included 2, 3, 4, 5, 6, etc., and an "X" denoted consecutiveness (For example, 2X means two consecutive matching striae).

The second objective of the research was to examine the CMS criteria in relation to AFTE Theory of Identification and conclusions used by firearm examiners within the field of firearm and tool mark analysis. According to the AFTE Theory of Identification, there are three conclusions that can be reached by firearm examiners in the microscopic comparison of tool marks; these are Identification, Inconclusive, and Elimination. The current CMS criteria only provide a guideline that addresses identification and elimination for firearm examinations, leaving the examiner to determine what an “Inconclusive” result would be. In this research, the three AFTE Range of conclusions were addressed by examining the frequency of occurrence of different groups of consecutive matching striae.

Furthermore, due to CMS criteria previously being applied to revolvers and pistols, two rifles of the same make and model were also selected to determine the reliability of CMS for these weapons as well. The test-fired samples were acquired through use of the Firearm and Tool Mark Section at the Oklahoma State Bureau of Investigation (OSBI).

Ten pairs of firearms were used in this research:

1. Raven MP-25 (serial #: 1395615)
2. Raven P-25 (serial #: 096500)
3. Davis P-380 (serial #: AP219369)

4. Davis P-380 (serial #: AP352200)
5. Lorcin L380 (serial #: 135891)
6. Lorcin L380 (serial #: 094662)
7. Bryco 9 mm 48’ (serial #: 086997)
8. Bryco 9 mm 59’ (serial #: 938352)
9. Ruger 9 mm P-89 (serial #: 307-57859)
10. Ruger 9 mm P-89 (serial #: 304-69928)
11. S&W 9 mm Model: 669 (serial #: TBT8371)
12. S&W 9 mm Model: 5903 (serial #: VBE0226)
13. Rossi-Amadeo Revolver M971 (Serial #: F127871)
14. Rossi-Amadeo Revolver M971 (Serial #: AA154267)
15. Ruger .40 P-94 (serial #: 340-66128)
16. Ruger .40 P-94 (serial #: 340-98441)
17. Ruger .45 P-90 (serial #: 661-91395)
18. Ruger .45 P-90 (serial #: 663-52119)
19. MAK 90 Rifle 7.62×39mm (serial #: 025178)
20. MAK 90 Rifle 7.62×39mm (serial #: 9492668)

CHAPTER FOUR:

RESULTS OF THE DATA

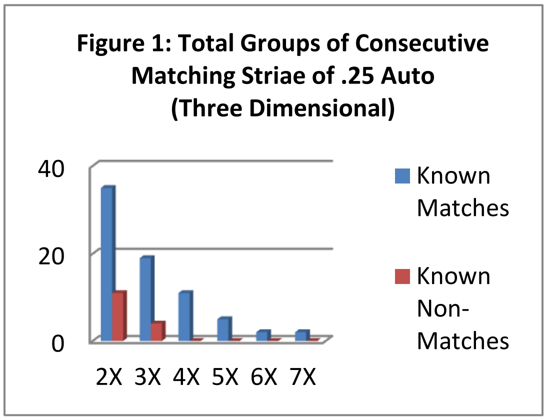
Two phases of results were reported in this research. First phase results address the number of consecutive matching striae groups as tabulated for known match and known non-match comparisons through microscopic examination. These results were utilized to determine the reliability of CMS criteria in its current form. Second phase results consist of the frequency of occurrence for consecutive matching striae groups as tabulated through observation in an attempt to provide quantitative data in relation to the AFTE Range of Conclusions. The ten best known match comparisons and known non-match comparisons for each gun were used for data collection and tabulation.

.25 Auto Data Results (Raven)

In three dimensional viewing, the most common consecutive groups were in sets of two, with 35 occurring in known match comparisons and 11 occurring in known non-match comparisons. The consecutive matching striae groups that were observed beyond 3X in known match comparisons were 4X, 5X, 6X, and 7X. No consecutive matching striae groups beyond 3X were observed in known non-match comparisons. By computing the frequency of occurrence for consecutive matching striae groups in 3D viewing, one group of 4X or two groups of 3X has a

100% chance of identifying all known match comparisons, while no misidentifications of any known non-match comparisons occurred. Based on this data set, the “one group of 4X or two groups of 3X” criterion can be used to distinguish a match from non-match. One group of 3X or two groups of 2X has a 100% chance of identifying all known match comparisons; however, there is a 40% chance of misidentifying a known non-match comparison. The “one group of 3X and two groups of 2X” criterion better represents an “Inconclusive” result established through this data set (see Table 1 and 2).

In two dimensional viewing, the most common consecutive groups were in sets of two, with 25 occurring in known match comparisons and 21 occurring in known non-match comparisons. The consecutive matching striae groups that were observed beyond 3X in known match comparisons were 4X, 5X, 6X and 7X. No consecutive matching striae groups beyond 3X were observed in known non-match comparisons. By computing the frequency of occurrence for consecutive matching striae groups in 2D viewing, one group of 4X has a 90% chance of correctly identifying all known match comparisons, while no misidentifications of any known non-match comparisons occurred. Based on this data set, the “one group of 4X” criterion can be used to distinguish a match from non-match. One group of 3X or two groups of 2X has a 100% chance of identifying all known match comparisons; however, it also has a 30% chance of misidentifying known non-match comparisons. The “one group of 3X or two groups of 2X” criterion better represents an “Inconclusive” result (see Table 1 and 2).



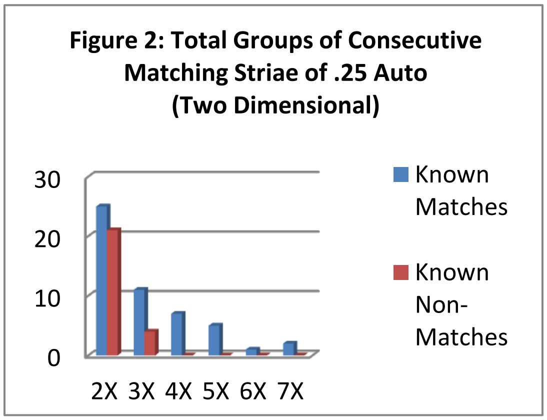
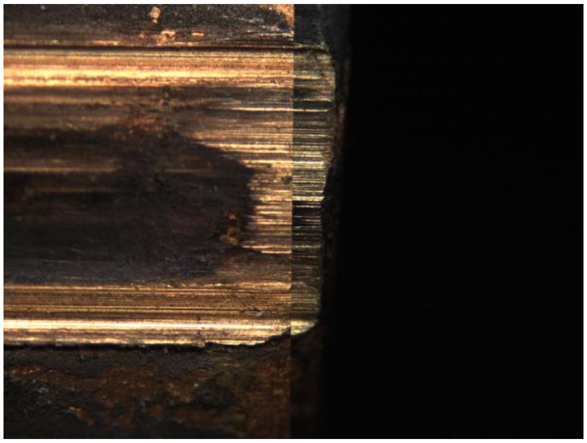


Table 1: Total Groups of Consecutive Matching Striae of .25 Auto (Raven)

Data	KM-3D	KNM-3D	KM-2D	KNM-2D
2X	35	11	25	21
3X	19	4	11	4
4X	11	0	7	0
5X	5	0	5	0
6X	2	0	1	0
7X	2	0	2	0
Total	74	15	51	25



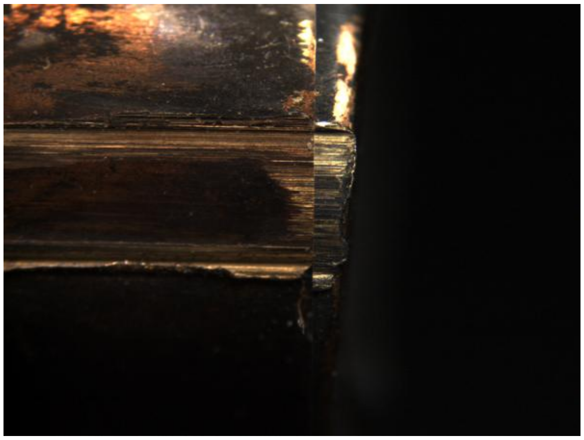


Photo 1: .25 Auto Known Match Comparison **Photo 2: .25 Auto Known Non-Match Comparison**

Table 2: The Frequency of Occurrence for Consecutive Matching Striae Groups of .25 Test Fires

3D	Known Match	Known Non-Match	Conclusion
One group of 4X	100%	0	Identification
One group of 3X or two groups of 2X	100%	40%	Inconclusive
Anything outside these criteria			Elimination
2D	Known Match	Known Non-Match	Conclusion
One group of 4X	90%	0	Identification
One group of 3X	100%	30%	Inconclusive
Anything outside these criteria			Elimination

380 Auto Data Results (Lorcin L-380 and Davis P-380)

In three dimensional viewing, the most common consecutive groups were in sets of two, with 39 occurring in known match comparisons and 23 occurring in known non-match comparisons. The consecutive groups that were observed beyond 3X in known match comparisons were 4X and 5X. No consecutive groups beyond 3X were observed in known non-match comparisons. By computing the frequency of occurrence for consecutive matching striae groups in 3D viewing, one group of 5X or two groups of 3X has a 71% chance of identifying all known match comparisons, while no misidentifications of any known non-match comparisons occurred. Based on this data set, the “one group of 5X or two groups of 3X” criterion can be used to distinguish a match from non-match. One group of 3X or two groups of 2X has a 100% chance of identifying all known match comparisons; however, there is a 29% chance of misidentifying known non-match comparisons. The “one group of 3X or two groups of 2X” criterion better represents an “Inconclusive” result for this data set (see Table 3 and 4).

In two dimensional viewing, the most common consecutive groups were in sets of two, with 35 occurring in known match comparisons and 28 occurring in known non-match comparisons. The consecutive group that was observed beyond 4X in known match comparisons was 5X. No consecutive groups beyond 4X were observed in known non-match comparisons. By computing the frequency of occurrence for consecutive matching striae groups in 2D viewing, one group of 5X has a 12% chance of identifying all known match comparisons, while no misidentifications of any known non-match comparisons occurred. Based on this data set, the “one group of 5X” criterion can be used to distinguish a match from non-match. One group of 3X has a 100% chance of identifying all known match comparisons; however, there is a 18% chance of misidentifying known non-match comparisons. The “one group of 3X” criterion better represents an “Inconclusive” result (see Table 3 and 4).

Table 3: Total Groups of Consecutive Striae of 380 Auto Test Fires

Data	KM-3D	KNM-3D	KM-2D	KNM-2D
2X	39	23	35	28
3X	25	3	21	3
4X	6	0	5	2
5X	1	0	2	0
6X	0	0	0	0
7X	0	0	0	0
Total	71	27	63	33

Figure 3: Total Groups of Consecutive Matching Striae of 380 (Three Dimensional)

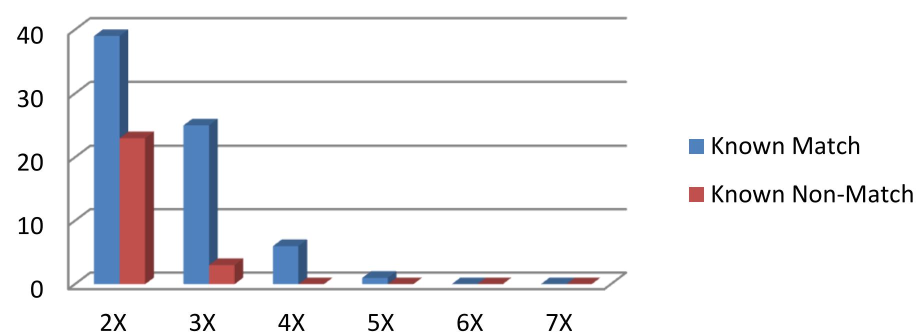


Figure 4: Total Groups of Consecutive Matching Striae of 380 (Two Dimensional)

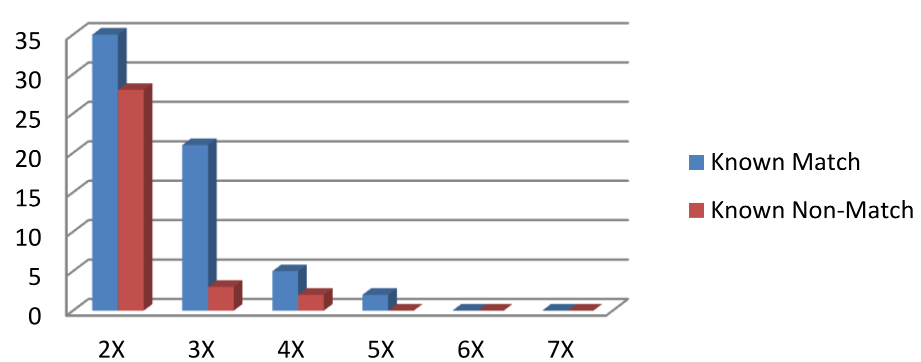


Table 4: The Frequency of Occurrence for Consecutive Matching Striae Groups of 380

3D	Known Match	Known Non-Match	Conclusion
One group of 5X or two groups of 3X	71%	0	Identification
One group of 3X or two groups of 2X	100%	29%	Inconclusive
Anything outside these criteria			Elimination
2D	Known Match	Known Non-Match	Conclusion
One group of 5X	12%	0	Identification
One group of 3X	100%	18%	Inconclusive
Anything outside these criteria			Elimination

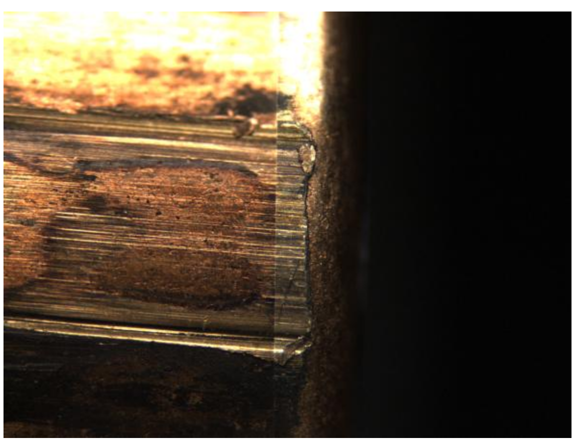


Photo 3: 380 Auto Known Match Comparison

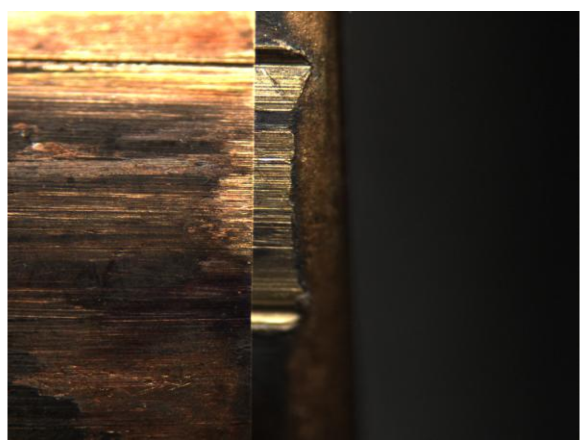


Photo 4: 380 Auto Known Non-Match Comparison

9mm Data Results (Bryco, Ruger P-89 and S&W)

In three dimensional viewing, the most common consecutive groups were in sets of two, with 68 occurring in known match comparisons and 39 occurring in known non-match comparisons. The consecutive matching striae groups that were observed beyond 3X in known match comparisons were 4X, 5X, 6X, and 7X. No consecutive matching striae groups beyond 3X were observed in known non-match comparisons. By computing the frequency of occurrence for consecutive matching striae groups in 3D viewing, one group of 4X has a 76% chance of identifying all known match comparisons, while no misidentifications of any known non-match comparisons occurred. Based on this data set, the "one group of 4X" criterion can be used to distinguish a match from non-match. One group of 3X or two groups of 2X has a 100% chance of identifying all known match comparisons; however, there is a 52% chance of misidentifying known non-match comparisons. The "one group of 3X or two groups of 2X" criterion better represents an "Inconclusive" result established through this data set (see Table 5 and 6).

In two dimensional viewing, the most common consecutive groups were in sets of two, with 55 occurring in known match comparisons and 48 occurring in known non-match comparisons. The consecutive matching striae groups that were observed beyond 4X in known match comparisons were 5X, 6X, and 8X. No consecutive matching striae groups beyond 4X were observed in known non-match comparisons. By computing the frequency of occurrence for consecutive matching striae groups in 2D viewing, one group of 5X or two groups of 4X has a 48% chance of identifying all known match comparisons, while no misidentifications of any known non-match comparisons occurred. The “one group of 5X or two groups of 4X” criterion can be used to distinguish a match from non-match in this data set. Two groups of 3X has a 100% chance of identifying all known match comparisons; however, there is a 8% chance of misidentifying known non-match comparisons. The “two groups of 3X” criterion better represents an “Inconclusive” result (see Table 5 and 6).

Figure 5: Total Groups of Consecutive Matching Striae of 9mm (Three Dimensional)

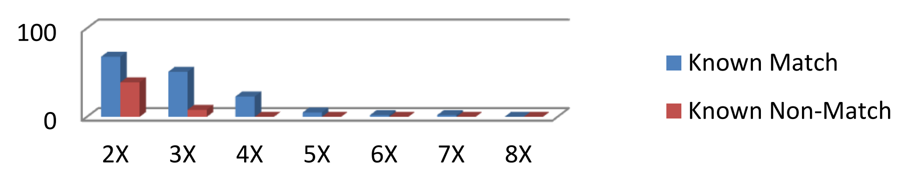


Figure 6: Total Groups of Consecutive Matching Striae of 9mm (Two Dimensional)

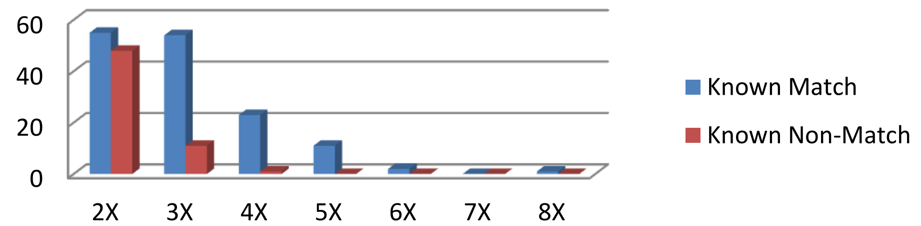


Table 5: Total Groups of Consecutive Matching Striae of 9mm Test Fires

Data	KM-3D	KNM-3D	KM-2D	KNM-2D
2X	68	39	55	48
3X	51	8	54	11
4X	23	0	23	1
5X	5	0	11	0
6X	2	0	2	0
7X	2	0	0	0
8X	0	0	1	0
Total	151	47	149	60

Table 6: The Frequency of Occurrence for Consecutive Matching Striae Groups of 9mm Test Fires

3D	Known Match	Known Non-Match	Conclusion
One group of 4X	76%	0	Identification
One group of 3X or two groups of 2X	100%	52%	Inconclusive
Anything outside these criteria			Elimination
2D	Known Match	Known Non-Match	Conclusion
One group of 5X or two groups of 4X	48%	0	Identification
Two groups of 3X	100%	8%	Inconclusive
Anything outside these criteria			Elimination

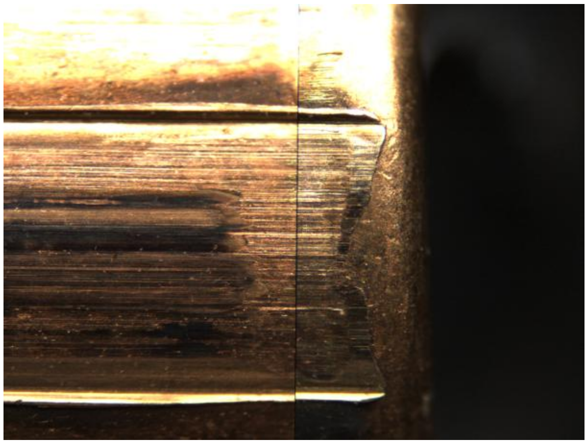


Photo 5: 9mm S&W Known Match Comparison

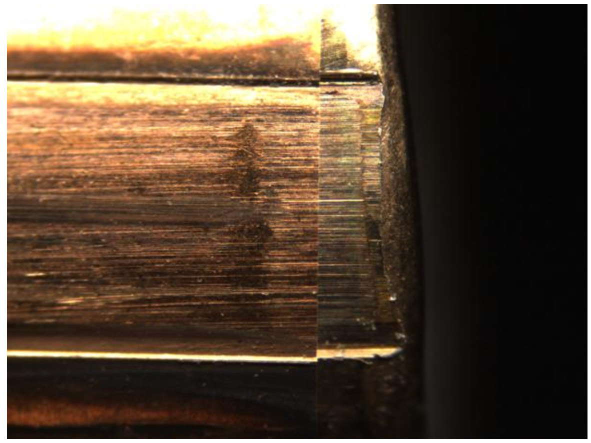


Photo 6: 9mm S&W Known Non-Match Comparison

38 SPL Data Results (Rossi-Amadeo)

In three dimensional viewing, the most common consecutive groups were in sets of two, with 31 occurring in known match comparisons and 17 occurring in known non-match comparisons. The consecutive matching striae groups that were observed beyond 3X in known match comparisons were 4X, 5X, and 6X. No consecutive matching striae groups beyond 4X were observed in known non-match comparisons. By computing the frequency of occurrence for consecutive matching striae groups in 3D viewing, one group of 4X or two groups of 3X has a 70% chance of identifying all known match comparisons, while no misidentifications of any known non-match comparisons occurred. Based on this data set, the “one group of 4X or two groups of 3X” criterion can be used to distinguish a match from non-match. One group of 3X has a 100% chance of identifying all known match comparisons; however, there is a 20% chance of misidentifying known non-match comparisons. The “one group of 3X” criterion better represents an “Inconclusive” result established through this data set (see Table 7 and 8).

In two dimensional viewing, the most common consecutive groups were in sets of two, with 22 occurring in known match comparisons and 17 occurring in known non-match comparisons. The consecutive matching striae groups that were observed beyond 3X in known match comparisons were 4X and 5X. No consecutive matching striae groups beyond 3X were observed in known non-match comparisons. By computing the frequency of occurrence for consecutive matching striae groups in 2D viewing, one group of 5X or two groups of 4X has a 70% chance of identifying all known match comparisons, while no misidentifications of any known non-match comparisons occurred. Based on this data set, the “one group of 5X or two groups of 4X” criterion can be used to distinguish a match from non-match. One group of 3X has a 100% chance of identifying all known match comparisons; however, there is a 50% chance of misidentifying known non-match comparisons. The “one group of 3X” criterion better represents an “Inconclusive” result (see Table 7 and 8).

Figure 7: Total Groups of Consecutive Matching Striae of 38 SPL (Three Dimensional)

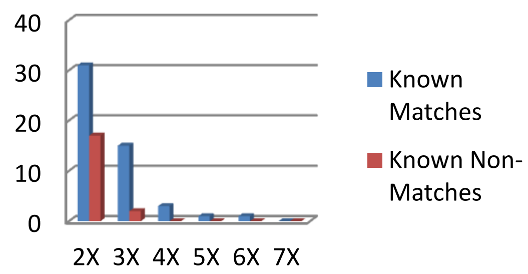


Figure 8: Total Groups of Consecutive Matching Striae of 38 SPL (Two Dimensional)

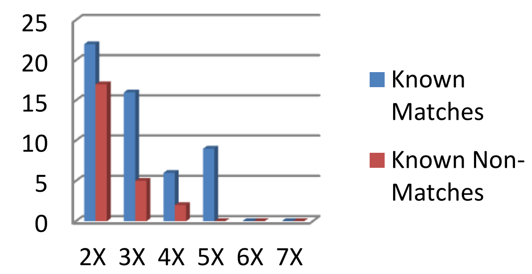


Table 7: Total Groups of Consecutive Matching Striae of 38 SPL (Rossi-Amadeo)

Data	KM-3D	KNM-3D	KM-2D	KNM-2D
2X	31	17	22	17
3X	15	2	16	5
4X	3	0	6	2
5X	1	0	9	0
6X	1	0	0	0
7X	0	0	0	0
Total	51	19	53	24

Photo 7: 38 SPL Known Match Comparison

Photo 8: 38 SPL Known Non-Match Comparison

Table 8: The Frequency of Occurrence for Consecutive Matching Striae Groups of 38 SPL

3D	Known Match	Known Non-Match	Conclusion
One group of 4X or two groups of 3X	70%	0	Identification
One group of 3X	100%	20%	Inconclusive
Anything outside these criteria			Elimination
2D	Known Match	Known Non-Match	Conclusion
One group of 5X or two groups of 4X	70%	0	Identification
One group of 3X	100%	50%	Inconclusive
Anything outside these criteria			Elimination

.40 JHP Data Results (S&W)

In three dimensional viewing, the most common consecutive groups were in sets of two, with 16 occurring in known match comparisons and 24 occurring in known non-match comparisons. The consecutive matching striae groups that were observed beyond 3X in known match comparisons were 4X, 5X, 6X, 8X, and 11X. No consecutive matching striae groups beyond 3X were observed in known non-match comparisons. By computing the frequency of occurrence of consecutive matching striae groups in 3D viewing, one group of 4X has a 80%

chance of identifying all known match comparisons, while no misidentifications of any known non-match comparisons occurred. Based on this data set, the “one group of 4X” criterion can be used to distinguish a match from non-match. Two groups of 3X has a 100% chance of identifying all known match comparisons; however, there is a 10% chance of misidentifying known non-match comparisons. The “two groups of 3X” criterion better represents an “Inconclusive” result established through this data set (see Table 9 and 10).

In two dimensional viewing, the most common consecutive groups were in sets of two, with 18 occurring in known match comparisons and 25 occurring in known non-match comparisons. The consecutive matching striae groups that were observed beyond 4X in known match comparisons were 5X, 6X, 7X, 8X, 10X, and 12X. No consecutive matching striae groups beyond 4X were observed in known non-match comparisons. By computing the frequency of occurrence for consecutive matching striae groups in 2D viewing, one group of 5X has a 90% chance of identifying all known match comparisons, while no misidentifications of any known non-match comparisons occurred. Based on this data set, the “one group of 5X” criterion can be used to distinguish a match from non-match. One group of 4X has a 100% chance of identifying all known match comparisons; however, there is a 30% chance of misidentifying known non-match comparisons. The “one group of 4X” criterion better represents an “Inconclusive” result (see Table 9 and 10).

Figure 9: Total Groups of Consecutive Matching Striae of .40 (Three Dimensional)

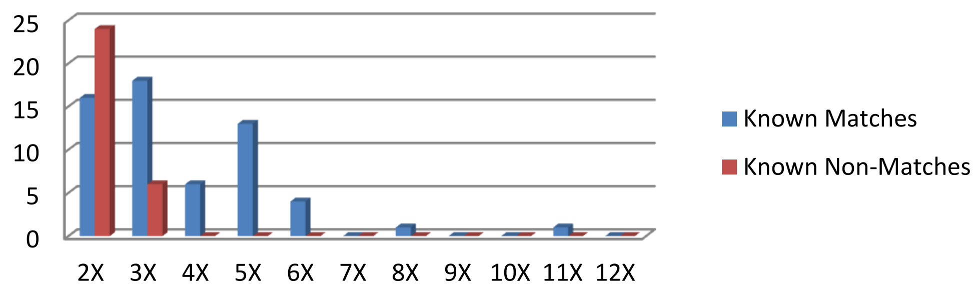
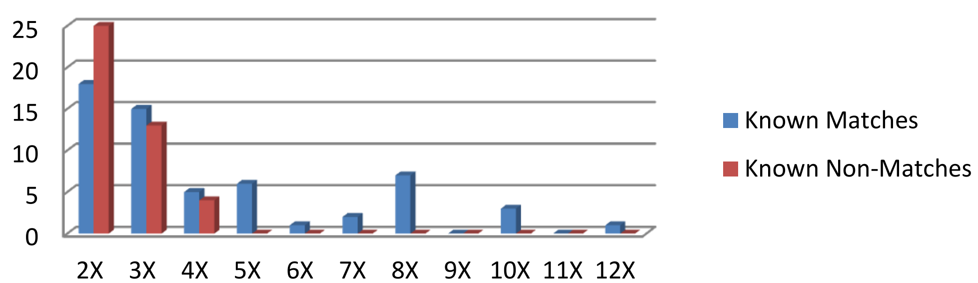


Figure 10: Total Groups of Consecutive Matching Striae of .40 (Two Dimensional)



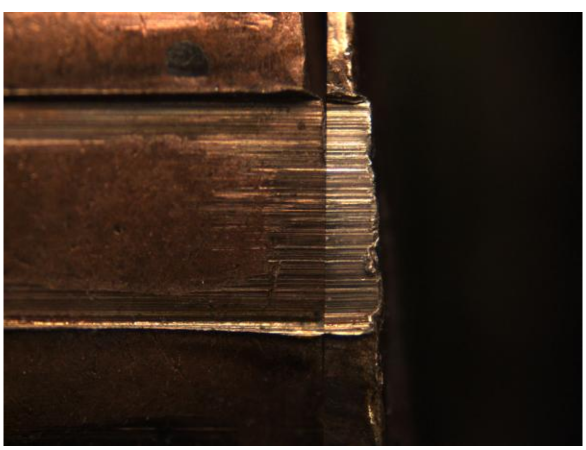


Photo 9: .40 S&W Known Match Comparison

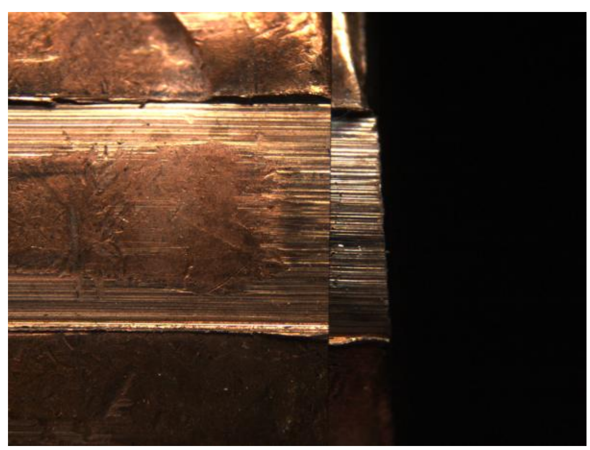


Photo 10: .40 S&W Known Non-Match Comparison

Table 9: Total Groups of Consecutive Matching Striae of .40 JHP (S&W)

Data	KM-3D	KNM-3D	KM-2D	KNM-2D
2X	16	24	18	25
3X	18	6	15	13
4X	6	0	5	4
5X	13	0	6	0
6X	4	0	1	0
7X	0	0	2	0
8X	1	0	7	0
9X	0	0	0	0
10X	0	0	3	0
11X	1	0	0	0
12X	0	0	1	0
Total	59	30	58	42

Table 10: The Frequency of Occurrence for Consecutive Matching Striae Groups of .40

3D	Known Match	Known Non-Match	Conclusion
One group of 4X	80%	0	Identification
Two groups of 3X	100%	10%	Inconclusive
Anything outside these criteria			Elimination
2D	Known Match	Known Non-Match	Conclusion
One group of 5X	90%	0	Identification
One group of 4X	100%	30%	Inconclusive
Anything outside these criteria			Elimination

.45 Auto Data Results (Ruger P90)

In three dimensional viewing, the most common consecutive groups were in sets of two, with 23 occurring in known match comparisons and 19 occurring in known non-match comparisons. The consecutive matching striae groups that were observed beyond 3X in known match comparisons were 4X, 5X, and 7X. No consecutive matching striae groups beyond 4X were observed in known non-match comparisons. By computing the frequency of occurrence for consecutive matching striae groups in 3D viewing, one group of 5X or two groups of 3X has a 90% chance of identifying all known match comparisons, while no misidentifications of any known non-match comparisons occurred. Based on this data set, the “one group of 5X or two groups of 3X” criterion can be used to distinguish a match from non-match comparisons. One group of 4X has a 90% chance of identifying all known match comparisons; however, there is a 10% chance of misidentifying known non-match comparisons. The “one group of 4X” criterion better represents an “Inconclusive” result established through this data set (see Table 11 and 12).

In two dimensional viewing, the most common consecutive groups were in sets of two, with 30 occurring in known match comparisons and 19 occurring in known non-match comparisons. The consecutive matching striae groups that were observed beyond 4X in known match comparisons were 6X and 8X. No consecutive matching striae groups beyond 4X were observed in known non-match comparisons. By computing the frequency of occurrence for consecutive matching striae groups in 2D viewing, one group of 5X or two groups of 3X has a 90% chance of identifying all known match comparisons, while no misidentifications of any known non-match comparisons occurred. Based on this data set, the "one group of 5X or two groups of 3X" criterion can be used to distinguish a match from non-match. One group of 3X has a 100% chance of identifying all known match comparisons; however, there is a 40% chance of misidentifying known non-match comparisons. The "one group of 3X" criterion better represents an "Inconclusive" result (see Table 11 and 12).

Figure 11: Total Groups of Consecutive Matching Striae of .45 Auto (Three Dimensional)

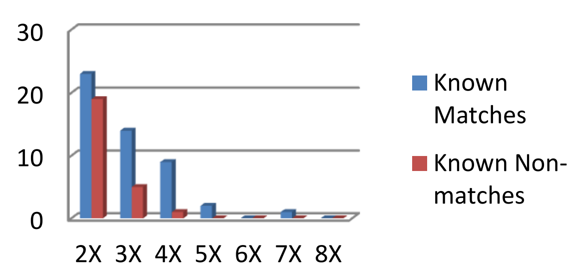


Figure 12: Total Groups of Consecutive Matching Striae of .45 Auto (Two Dimensional)

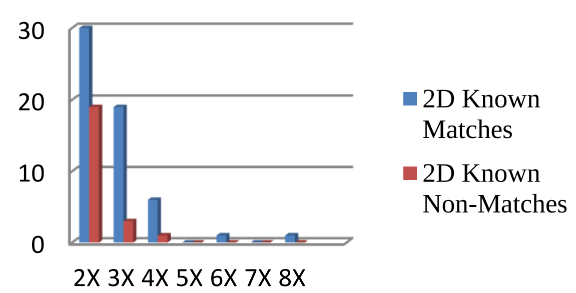


Table 11: Total Groups of Consecutive Matching Striae of .45 Auto (Ruger P90)

Data	KM-3D	KNM-3D	KM-2D	KNM-2D
2X	23	19	30	19
3X	14	5	19	3
4X	9	1	6	1
5X	2	0	0	0
6X	0	0	1	0
7X	1	0	0	0
8X	0	0	1	0
Total	49	25	57	23

Table 12: The Frequency of Occurrence for Consecutive Matching Striae Groups of .45

3D	Known Match	Known Non-Match	Conclusion
One group of 5X or two groups of 3X	90%	0	Identification
One groups of 4X	90%	10%	Inconclusive
Anything outside these criteria			Elimination
2D	Known Match	Known Non-Match	Conclusion
One group of 5X or two groups of 3X	90%	0	Identification
One group of 3X	100%	40%	Inconclusive
Anything outside these criteria			Elimination

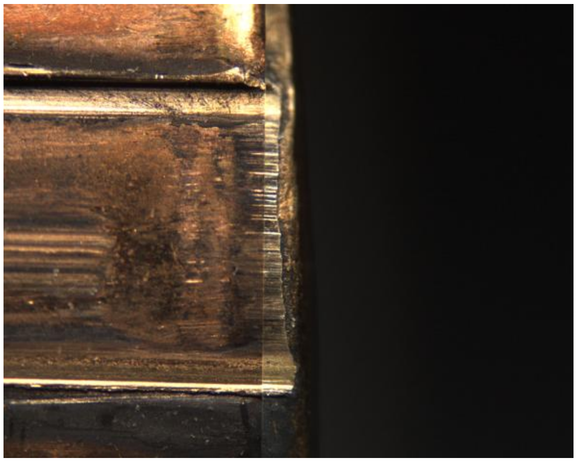


Photo 11: .45 Auto Known Match Comparison

Photo 12: .45 Auto Known Non-Match Comparison

7.62×39mm FMJ Data Results (MAK90)

In three dimensional viewing, the most common consecutive groups were in sets of two, with 22 occurring in known match comparisons and 23 occurring in known non-match comparisons. The consecutive matching striae groups that were observed beyond 4X in known match comparisons were 5X and 6X. No consecutive matching striae groups beyond 4X were observed in known non-match comparisons. By computing the frequency of occurrence for consecutive matching striae groups in 3D viewing, one group of 5X or two groups of 4X has a 90% chance of identifying all known match comparisons, while no misidentifications of any known non-match comparisons occurred. Based on this data set, the "one group of 5X or two groups of 4X" criterion can be used to distinguish a match from non-match comparisons. One group of 4X or two groups of 3X has a 100% chance of identifying all known match comparisons; however, there is a 30% chance of misidentifying known non-match comparisons. The "one group of 4X or two groups of 3X" criterion better represents an "Inconclusive" result established through this data set (see Table 13 and 14).

In two dimensional viewing, the most common consecutive groups were in sets of two, with 25 occurring in known match comparisons and 22 occurring in known non-match comparisons. The consecutive matching striae groups that were observed beyond 4X in known match comparisons were 5X, 6X and 10X. No consecutive matching striae groups beyond 4X were observed in known non-match comparisons. By computing the frequency of occurrence for consecutive matching striae groups in 2D viewing, one group of 5X or two groups of 4X has a 90% chance of identifying all known match comparisons, while no misidentifications of any known non-match comparisons occurred. Based on this data set, the "one group of 5X or two groups of 4X" criterion can be used to distinguish a match from non-match. One group of 4X has a 100% chance of identifying all known match comparisons; however, there is a 30% chance of misidentifying known non-match comparisons. The "one group of 4X" criterion better represents an "Inconclusive" result (see Table 13 and 14).

Figure 13: Total Groups of Consecutive Matching Striae of 7.62 39mm FMJ Data Results (MAK90) (Three Dimensional)

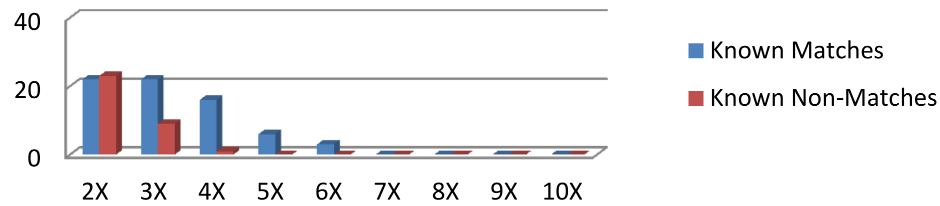


Figure 14: Total Groups of Consecutive Matching Striae of 7.62 39mm FMJ Data Results (MAK90) (Two Dimensional)

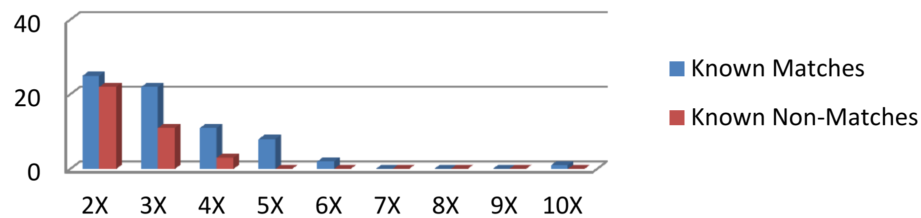


Table 13: Total Groups of Consecutive Matching Striae of 7.62×39mm FMJ

Data	KM-3D	KNM-3D	KM-2D	KNM-2D
2X	22	23	25	22
3X	22	9	22	11
4X	16	1	11	3
5X	6	0	8	0
6X	3	0	2	0
7X	0	0	0	0
8X	0	0	0	0
9X	0	0	0	0
10X	0	0	1	0
Total	69	33	69	36

Table 14: The Frequency of Occurrence for Consecutive Matching Striae Groups of 7.62×39mm

3D	Known Match	Known Non-Match	Conclusion
One group of 5X or two groups of 4X	90%	0	Identification
One groups of 4X or two groups of 3X	100%	30%	Inconclusive
Anything outside these criteria			Elimination
2D	Known Match	Known Non-Match	Conclusion
One group of 5X or two groups of 4X	90%	0	Identification
One group of 4X	100%	30%	Inconclusive
Anything outside these criteria			Elimination

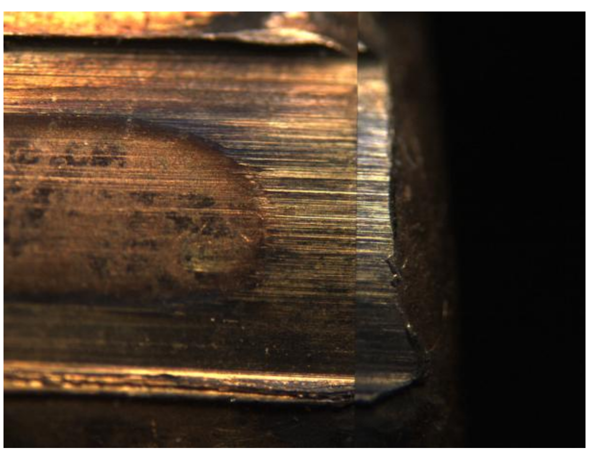


Photo 13: 7.62×39mm Known Match Comparison

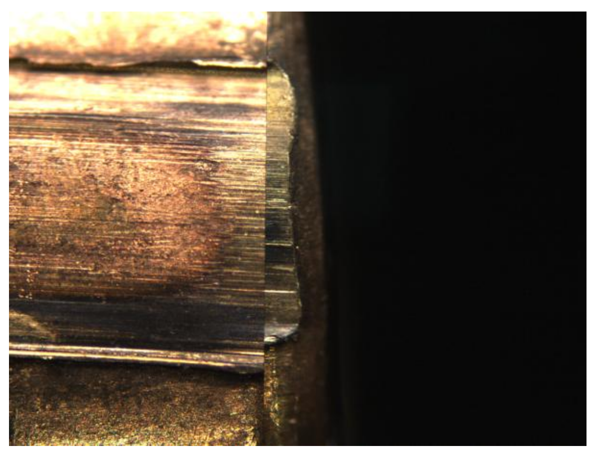


Photo 14: 7.62×39mm Known Non-Match Comparison

CHAPTER FIVE:

DISCUSSION

By applying the current CMS criteria for firearm identification as proposed by Biasotti and Murdock to the results of this research, no more than four consecutive matching striae can be seen in known non-match comparisons of all test fires. In addition, there were no misidentifications that occurred, but with current criteria some known match comparisons were excluded due to limited striae or other related factors such as slippage or damage.

Results of this study suggest new proposed criteria that would address false exclusions and can better be represented in both 2D and 3D viewing of tool marks. The new proposed criteria for all test fires in 3D viewing according to this data set is supported by statistical tabulation as being “one group of 5X or two groups of 4X.” This criterion has a 47% chance of identifying all known match comparisons, while not misidentifying any known non-match comparisons. The “one group of 5X or two groups of 4X” criterion can be used to identify all matches and prevent any misidentifications in comparisons. One group of 3X and two groups of 2X has a 100% chance of identifying all known match comparisons; however, there is a 63% chance of misidentifying a known non-match comparison. The “one group of 3X or two groups of 2X” criterion better represents an “Inconclusive” determination (see Table 15).

In two dimensional viewing, one group of 5X has a 46% chance of identifying all known match comparisons, while no misidentifications of any known non-match comparisons. One group of 3X or two groups of 2X has a 100% chance of identifying all known match comparisons; however, there is a 83% chance of misidentifying known non-match comparisons. Based on this data set, the "one group of 3X or two groups of 2X" criterion better represents as "Inconclusive" result (see Table 15).

Table 15: The Overall Frequency of Occurrence for Consecutive Matching Striae Groups

3D	Known Match	Known Non-Match	Conclusion
One group of five consecutive matching striae or two groups of four consecutive matching striae	47%	0	Identification
One group of three consecutive matching striae or two groups of two consecutive matching striae	100%	63%	Inconclusive
Anything outside these criteria			Elimination
2D	Known Match	Known Non-Match	Conclusion
One group of five consecutive matching striae	46%	0	Identification
One group of three consecutive matching striae or two groups of two consecutive matching striae	100%	83%	Inconclusive
Anything outside these criteria			Elimination

This research indicates that the current CMS criteria is restrictive for firearm identification in that it may eliminate some identifications in known match comparisons where only several striae are available for comparison, but this never results in a misidentification. In addition, Biasotti and Murdock's CMS criteria failed to identify what criteria represents an "Inconclusive" result. The data in this research provides more accurate outcomes and includes criteria for "Inconclusive" results.

CHAPTER SIX:

CONCLUSION

Based on the data obtained in this research, current CMS criteria in terms of two dimensional and three dimensional viewing were valid for firearm identification as such never resulted in any misidentifications in known non-match comparisons of all test fires. However, some known match comparisons were excluded when applying current CMS criteria; therefore, they were too restrictive. Furthermore, caliber was not a factor that influenced an identification using CMS criteria and the 7.62×39mm rifle bullets also met the criteria although CMS had never been evaluated using rifle bullets prior to this study. By tabulating the frequency of occurrence for consecutive matching striae groups in this research, new, less restrictive criteria for CMS were established as:

Two dimensional tool mark identifications are those that are present when one group of at least five consecutive matching striae appear in the same relative position. One group of three consecutive matching striae or two groups of two consecutive matching striae represent an "Inconclusive" result. Anything outside these criteria results in an "Elimination".

Three dimensional tool mark identifications are those that are present when one group of at least five consecutive matching striae, or two groups of four consecutive matching

striae appear in the same relative position. One group of three consecutive matching striae or two groups of two consecutive matching striae represent an "Inconclusive" result. Anything outside these criteria results in an "Elimination".

The data recorded in three dimensional comparisons were different from that in two dimensional comparisons because the quality of the image has greater impact on the striae observed through microscopic comparison. The quality of the barrel, the presence of slippage, as well as any damage to the bearing surface of the bullet affected the quality of striae produced in this study, which is consistent with case work.

This research is of critical importance in light of recent legal challenges to the objectivity of firearm and tool mark analysis, reliability of expert witness testimony, and a general skepticism of impression-based evidence. It is essential to demonstrate the reliability of consecutive matching striae criteria in order to determine its effectiveness, consistency, and reliability for use in criminal cases involving the analysis of firearms and tool marks. Future studies should conduct proper sample sizes of both known match pair samples and known non-match pair samples to firmly establish numerical models that coincide with the AFTE Range of Conclusions as stated in the proposed model of this research. Continued research of this nature will ultimately strengthen the reliability of CMS criteria and advance this forensic discipline.

REFERENCES

Biasotti, A.A., (1959) A Statistical Study of the Individual Characteristics of Fired Bullets. *Journal of Forensic Science*, *4*(1), 34-50.

Biasotti, A.A., & Murdock, J.E., (1997). Firearms and toolmark identification: Legal issues and scientific status. In *Modern Scientific Evidence: The Law and Science of Expert Testimony*, ed D.L. Faigman, D.H. Kay, M.J. Saks, and J. Sanders, 124 – 151. St Paul: West Publishing Co.

Cantor, D. (2010, May 4). An Arizona Assault Attorney Gains Leverage by Questioning Firearms Identification Evidence. Message posted to http://www.dmcantor.com/blog/

Daubert v. Merrell Dow Pharmaceuticals (92-102), 509 U.S. 579, 1993

Dillon, J. (n.d.) Firearm Examiner Training Module 13: Toolmark Identification. National Institute of Justice. Retrieved Nov. 20, 2010 from http://www.ojp.usdoj.gov/nij/

Dougherty, Paul M., (1969) Report on Two Early United States Firearms Identification Cases, *Journal of Forensic Science*, *14*(4) p. 453.

Forensic Firearms and Tool Marks Time Line. (n.d.). The Forensic Scientist. Retrieved Nov. 20, 2010, from http://www.quincy.ca/timelines/forensic_firearms_tool_marks.html

Goddard, Calvin H., (1979). Scientific Identification of Firearms and Bullets. *AFTE Journal, 11*(4), p. 97.

Heard, B., (2008). *Handbook of Firearms and Ballistics: Examining and interpreting forensic evidence*. (2nd ed.) West Sussex, UK: Blackwell Publishing

Miller, J., (2000). Criteria For Identification of Tool Marks Part 2: Single Land Impression Comparisons. *AFTE Journal*, *32*(2), 116-131.

Miller, J., (2001). An Examination of the Application of the Consecutive Criteria for Identification of Striated Toolmarks Using Bullets Fired From Ten Consecutively Rifled Barrels.' *AFTE Journal*, *33*(2), pp. 125-132.

Nichols, R. G. (1997). Firearm and tool mark identification criteria: a review of the literature. *Journal of Forensic Science, 42*(3): 466-74

Nichols, R. G. (2007). Defending the Scientific Foundations of Firearms and Tool Mark Identification Discipline: A Response to Recent Challenges. *Journal of Forensic Science*, *52*(6), 1414-1416.

Schwartz, A., (2005). A Systemic Challenge to the Reliability and Admissibility of Firearms and Tool Mark Identification. *The Columbia Science and Technology Law Review*, VI, 1-42.

Uchiyama, T., (1988a). A Criterion For Land Mark Identification. *AFTE Journal*, *20*(3), 236-251.

Uchiyama, T., (1992). The Probability of Corresponding Striae in Tool Marks. *AFTE Journal*, *24*(3), 273-290.

APPENDIX

DEFINITION OF TERMS

(Source: AFTE Glossary which has been accepted in the firearm and tool mark field.)

AFTE: The Association of Firearm and Tool Mark Examiners.

AFTE Theory of Identification: [a] The theory of identification as it pertains to the comparison of tool marks enables opinions of common origin to be made when the unique surface contours of two tool marks are in "sufficient agreement".

[b] This "sufficient agreement" is related to the significant duplication of random tool marks 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 it exceeds the best agreement demonstrated between tool marks known to have been produced by different tools and is consistent with the agreement demonstrated by tool marks known to have been produced by the same tool. The

statement that “sufficient agreement” exists between two tool marks means that the agreement 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.

[c] Currently the interpretation of individualization/identification is subjective in nature, founded on scientific principles and based on the examiner’s training and experience.

Bullet: A non-spherical projectile for use in a rifled barrel.

Caliber: The approximate diameter of the circle formed by the tops of the lands of a rifled barrel.

Class characteristics: Measurable features of a specimen which indicate a restricted group source. They result from design factors, and are therefore determined prior to manufacture.

Comparison microscope: Essentially two microscopes connected to an optical bridge which allows the viewer to observe two objects simultaneously with the same degree of magnification. This instrument can have a monocular or binocular eyepiece.

Firearm: An assembly of a barrel and action from which a projectile(s) is propelled by products of combustion.

Firearm identification: A discipline of forensic science whose primary concern is to determine if a bullet, cartridge case or other ammunition component was fired by a particular firearm.

Individual characteristics: Marks produced by the random imperfections or irregularities of tool surfaces. These random imperfections or irregularities are produced incidental to manufacture and/or caused by use, corrosion, or damage. They are unique to that tool and distinguish it from all other tools.

Subclass characteristics: Discernible surface features of an object, which are more restrictive than class characteristics in that they are:

1. Produced incidental to manufacture.
2. Are significant in that they relate to a smaller group source (a subset of the class to which they belong).
3. Can arise from a source which changes over time.

Striations: Contour variations, generally microscopic, on the surface of an object caused by a combination of force and motion where the motion is approximately parallel to the plane being marked. These marks can contain Class and/or Individual Characteristics.

Test bullet: Bullet fired into a bullet recovery system in a laboratory for comparison or analysis.