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Objective Analysis of Impressed Chisel Toolmarks

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ABSTRACT: Historical and recent challenges to the practice of comparative 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 toolmarks, a more complex form of toolmark, pose a more difficult test for the algorithm that was originally designed for striated toolmarks. Results show in this instance that the algorithm can statistically separate matching and nonmatching impression marks, providing further validation of the assumption that toolmarks are identifiably unique.

KEY WORDS: forensic science, statistical comparison, chisel, impression, algorithm, toolmark

Challenges to comparative forensic science have created the need for an objective means of toolmark identification to aid forensic examinations. These challenges, such as the 1993 Daubert v. Merrell Dow Pharmaceuticals, Inc. court case over admissibility of expert testimony or the more recent 2010 National Academy of Science (NAS) report challenging a "*lack"* of scientific background, have had profound impacts on the field of comparative forensic examination and resulted in many validation studies. Many of the studies, including this one, provide evidence for the primary assumption of comparative forensic science – every tool has a unique surface topography such that it can leave an identifiably unique toolmark.

Prior research that has been conducted with chisels involved the creation of striated chisel marks. By AFTE (Association of Firearm and Tool Mark Examiners) definition, striated toolmarks are created by force and movement of a tool in a direction approximately parallel to the surface being acted upon (1). Petraco et al. used 5 sequentially manufactured chisels to make 50 striated marks at 30° in a lead medium. Topographical data were obtained using a confocal microscope. Toolmarks were created by dragging the chisels across the substrate while using a jig for angular control. However this process resulted in patches of continuous striations that were not suitable for analysis with the available methods (2).

Zheng et al. also created striated chisel marks. Ten sequentially manufactured chisels were used to create striated toolmarks by using a jig to drag the tools against a copper substrate with a controlled force at a 90° angle. Two known and unknown marks were created for each tool, resulting in 40 total toolmarks. A stylus profilometer was used to obtain the topographical information. Using the cross correlation function (CCF), the unknown toolmarks were correctly identified to the chisels that created them after establishing a critical CCF value. The critical value was obtained with the known marks by comparing known matching and nonmatching toolmarks (3).

While many toolmark studies, and the previous research on chisel toolmarks, have focused on striated marks, little has been done with impressed chisel toolmarks. By AFTE definition, impressed toolmarks are created by force and movement of a tool in a direction approximately perpendicular to the surface being acted upon (1). A criminal could leave an impressed chisel mark while breaking into a safe (4) or a locked desk drawer.

The current study involves the analysis of 50 sequentially manufactured cold chisels (chisels designed for metal working at room temperature) that were used to create 500 impression toolmarks. In this case, the impressions from the sharpened tool sides were analyzed and not the impression due to the working edge of the tool. Impressions made from a blunted edge are often what are observed by forensic examiners. As the chisels in this study were acquired directly from the manufacturer and had not been used, the working edge had not been blunted by use. The toolmarks were compared using a statistical algorithm originally developed for the comparison of striated toolmarks. The algorithm, utilizing a Wilcoxon Rank Sum test statistic, has been used to statistically separate matching and nonmatching striated screwdriver marks (5) and quasi-striated plier marks (6) although complete separation was not achieved. It was also observed that the degree of statistical separation achievable between matching and nonmatching toolmarks decreased with increasing toolmark complexity – from the striated screwdriver marks to the quasi-striated plier marks. Impression toolmarks are more three-dimensional in character than striated toolmarks and pose an even more difficult test for the algorithm. Results of this study will show the algorithm's ability to statistically separate these matching and nonmatching impression marks.

Experimental Methodology

Fifty sequentially manufactured 1/4" cold chisels were obtained from Wilde Tool Company, Inc. To ensure sequentiality, the manufacturing process was observed by the researchers. It is well known that the manufacturing process influences the final tool topography (7), so a brief description of the relevant manufacturing processes is provided.

The material used to create the chisels is received as 5/16” cold rolled hexagonal bar. The bar is then sectioned into the necessary lengths to make the chisels. Each sectioned bar is hot forged on one end to create the functional end of the tool. After forging, the functional end (i.e. the eventual sharpened end) is trimmed to remove burrs and rough cut to the correct dimensions. The oxide scale is then abrasively blasted away. This is followed by an induction heat treatment and molten salt quench to obtain the final microstructure and desired mechanical properties. The chisels are then abrasively blasted a second time to remove residual salts or oxides. The functional end of the chisel then is sharpened via an abrasive wheel. Gauges are set in the process line to ensure consistent sharpening angles between chisels. The final abrasive wheel sharpening imparts the functional tool topography that would be expected to leave toolmarks at a crime scene. Since the chisels are held in place during sharpening and the abrasive moves in one direction, the functional tool topography is linear in nature.

Each chisel was placed into a numbered and enclosed plastic bag to ensure sequentiality was maintained. Additionally, a unique identification number was punched into the branded side of each chisel. Figure 1 shows an example of two chisels.

Figure 1: Example of two chisels used in the study. The impressed letters designate side A, the unmarked side is side B.

To create impression toolmarks, a jig was created to hold a chisel at a 90° angle relative to a lead substrate. Two two-pound weights and a sliding plate guided by rails were used to strike one end of the chisel and create an impression of the chisel's functional end. The weight was released onto the chisel from a height of 6" (the top of the jig's rails were designed to be 6" above the top of the chisel) resulting in an impact energy of 2.66 joules. Ten impression marks were made with each chisel, resulting in 500 total impressions. However, each chisel has two sides for a total of 1,000 toolmarks. Figure 2 shows an example of the jig and impression marks in a lead substrate. The tool side facing the branded surface of the tool was named the 'A' side of the tool while the opposite side was named 'B'.

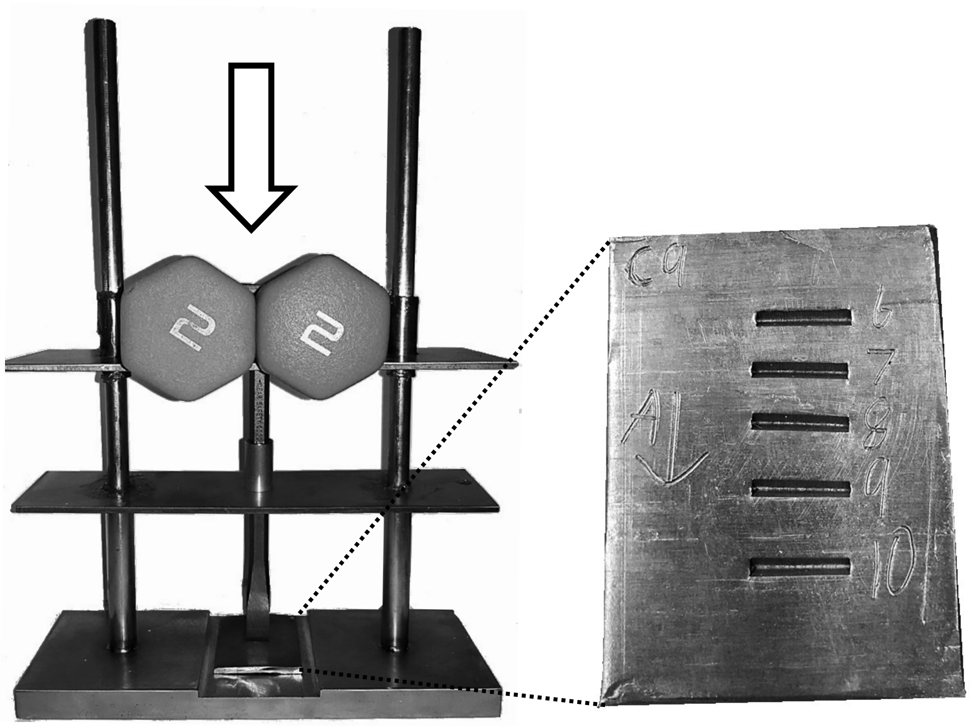

Figure 2: Example of the jig, the direction of applied force and example impression marks.

Toolmark topography information was obtained and digitized using an optical profilometer. Each impression was approximately a 1x10 mm area. A scanning magnification of ten times, vertical resolution of 0.997 microns and horizontal resolution of 3.91 microns was used during scanning. An example of a toolmark “as-scanned” is shown in Figure 3.

Figure 3: One impression mark as-scanned.

The algorithm used in this study, originally developed in (5), was designed to be used with approximately planar, striated toolmarks such as those created by screwdrivers. However, in Figure 3 it is clear that the toolmark has a 'V' cross section and there is extraneous data around the edges of the toolmark that should not be included in the analysis. To overcome these issues, internally developed software named MaskEditor was used to manually clean the data. MaskEditor contains a "painting" tool that allows a user to mask over unneeded data. The masking process, although manual, is not tedious because the program is designed to use the largest contiguous region of data. The unnecessary data is not deleted but simply ignored during analysis. MaskEditor was also useful for extracting the two planar regions of the toolmarks. The user could carefully mask over all but half of the toolmark, leaving just one planar section. The unmasked planar section is then leveled making it suitable for analysis. Using this procedure, each impression mark was cleaned twice to extract the 'A' and 'B' planar sides of the toolmark. The masking and extraction of one toolmark is shown in Figure 4 – the solid line along the planar section corresponds to the topographical profile shown adjacent to it.

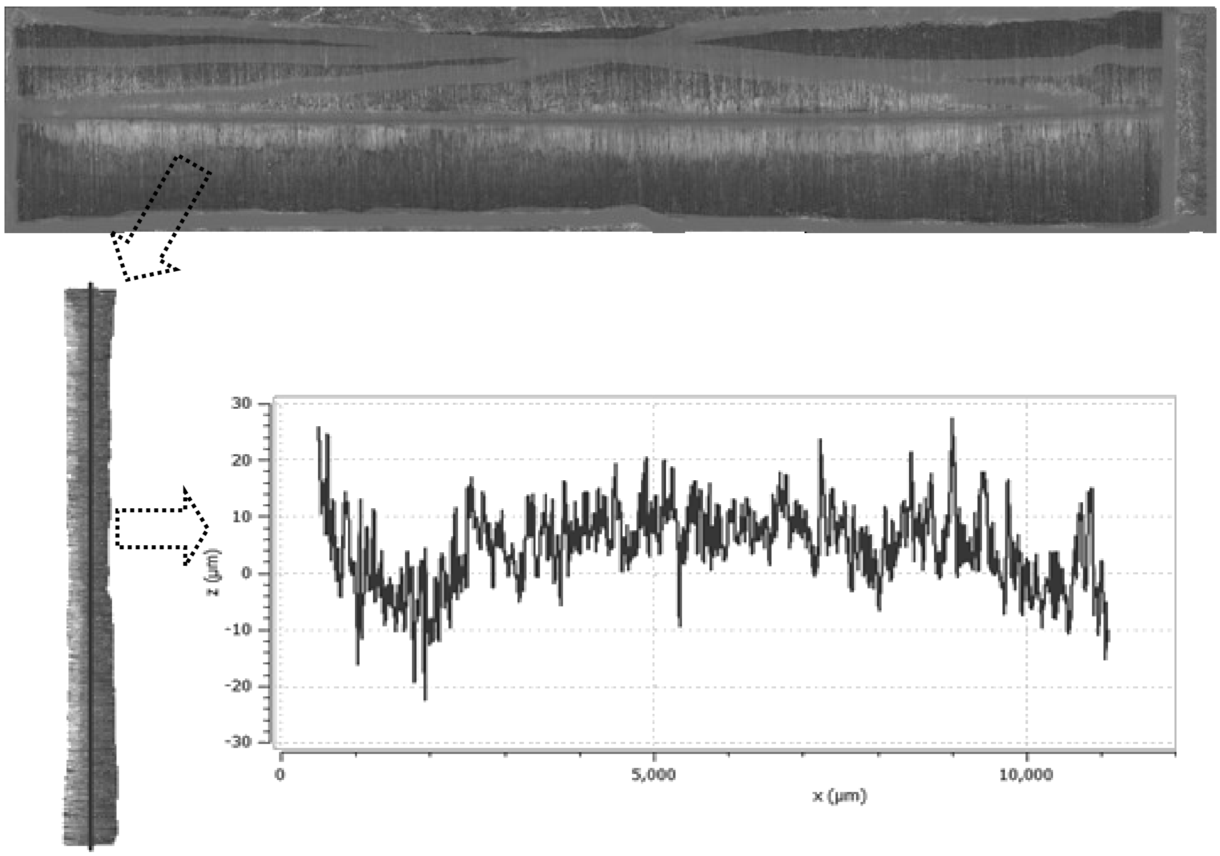

Figure 4: Masking process and extraction of planar toolmark.

With the data cleaning complete, the toolmarks were ready for analysis. Algorithmic comparisons were performed between two 2D profiles from approximately the center of each planar section. The computer algorithm statistically compares both profiles and outputs a single value - referred to as a T1 value. For full details on how the algorithm operates, the reader is referred to (5, 8). The T1 value, due to issues of the matching pair statistical distribution dependence on a variety of factors (9), cannot be used to declare a definitive match. However, a large T1 value indicates a high degree of correlation (consistent with matching toolmarks) while low, zero and negative T1 values indicate little to no statistical correlation (consistent with nonmatching toolmarks). Three different algorithm parameter settings (500-500, 750-750 and 1000-1000 pixels) were used for comparisons. The parameter settings were the pixel-widths of the search and validation window sizes (5). The window sizes correspond to the length of the topographical profile that computations were performed on at a given point in time during algorithm operation. It is known that different parameter settings (and varying search and validation window size ratios) can affect the results, thus three different settings were used to ensure consistency (6).

Three types of comparisons were performed for this analysis. Set 1 comparisons were performed between all matching toolmarks. For example the first toolmark, Chisel 1 side 'A' replicate 1 (C1A1) was compared to its nine replicates. Next C1A2 (the second replicate) was compared to its nine replicates. This procedure was repeated until all 'A' and 'B' side matching replicates had been compared (4500 comparisons). Set 2 comparisons were performed between the opposite sides of the same chisel for all replicates – e.g. C1A1 compared to C1B1 and their replicates (5000 comparisons). These toolmarks are expected to be nonmatching and could demonstrate that each side of the chisel effectively appears to be a different tool. Finally, Set 3 comparisons were performed between all of the nonmatching toolmarks of sequential chisels – e.g. C1A1 was compared to C2A1 and their replicates followed by C3A1 being compared to C4A1 and their replicates and so forth. This procedure was repeated for Set 3 so 'A' to 'A', 'A' to 'B', and 'B' to 'B' side comparisons were completed (7500 comparisons). A total of 17,000 comparisons were performed for each parameter setting and a total of 51,000 statistical comparisons were performed in this analysis.

Results

The data from the comparisons were organized and Figures 5-7 show the box and whisker plots for comparison Sets 1-3 for each parameter setting. The solid black line represents the median value, while the lower and upper bounds of the box represent quartiles. The whiskers are within one and a half times the interquartile range and outliers are signified by unfilled circles.

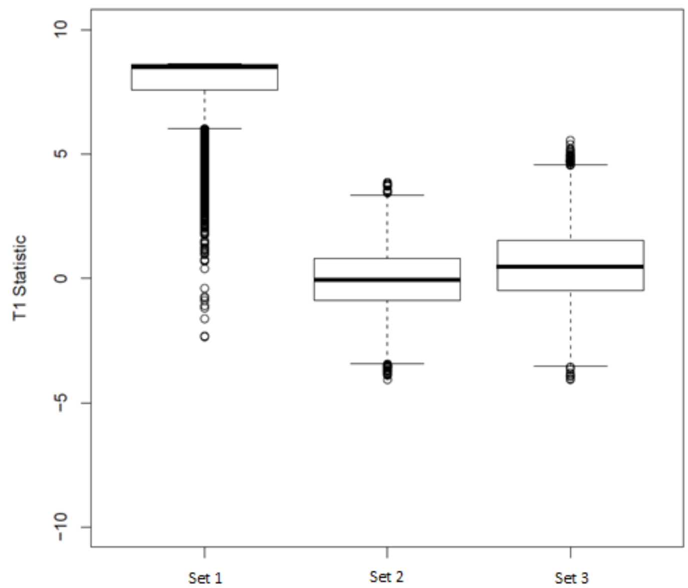

Figure 5: Statistical results using the 500-500 pixel-width parameter setting.

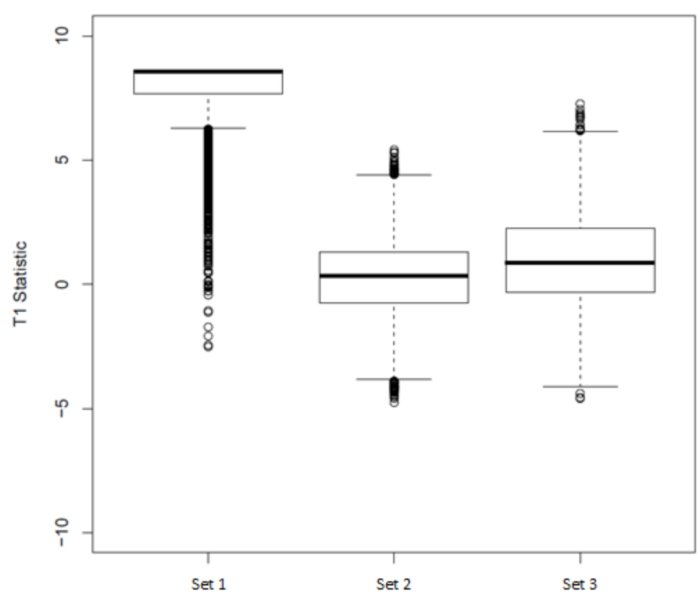

Figure 6: Statistical results using the 750-750 pixel-width parameter setting.

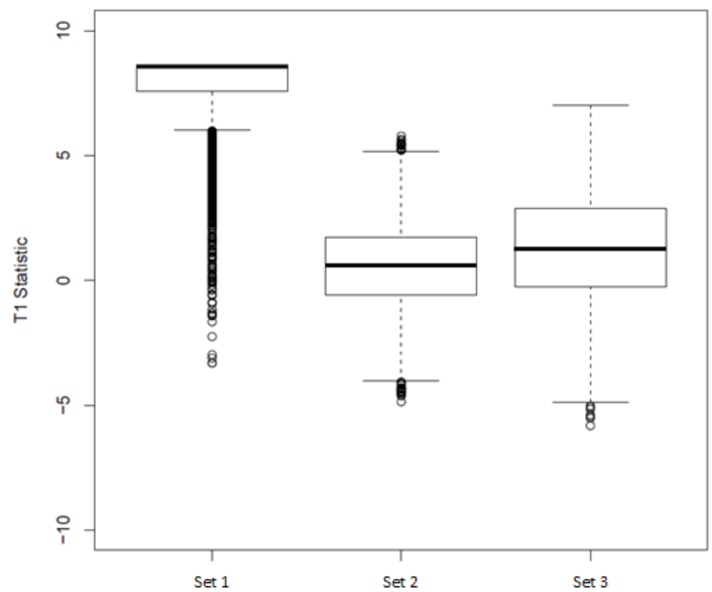

Figure 7: Statistical results using the 1000-1000 pixel-width parameter setting.

Discussion

Data from Set 1 comparisons for all parameter settings were relatively high T1 values, consistent with a high degree of correlation and matching pairs of toolmarks. The high degree of correlation present for the majority of the Set 1 comparisons has caused the median, upper bound and upper whisker to visually blend together. Sets 2 and 3 exhibited low to negative T1 values, consistent with little to no statistical correlation and nonmatching toolmarks as expected. The results are similar for all parameter settings, but complete separation between matching and nonmatching toolmarks, excluding outliers, was only achieved with the 500-500 pixel-width parameter setting.

Many outliers were observed, with the majority of outliers occurring in Set 1 comparisons, and a systematic cause was not found. The root cause may be due to the fact that the applied algorithm was not designed for this type of toolmark. A number of observations - listed below - were also made that could contribute to the number of outliers.

1. The jig used to hold the chisels cannot hold them perfectly orthogonal to the substrate for each replicate; there are a couple degrees of angular variation possible.
2. The struck end of the chisel is not perfectly flat for all chisels (see Figure 8). It is possible for the chisel to be struck asymmetrically causing further variation in toolmark replicates. While this would likely not inhibit the chisels' primary work function, in the case of making replicate toolmarks it could have an effect.
3. The sliding plate cannot strike the chisel perfectly orthogonally for each replicate. The sliding plate also has a couple degrees of angular variation.

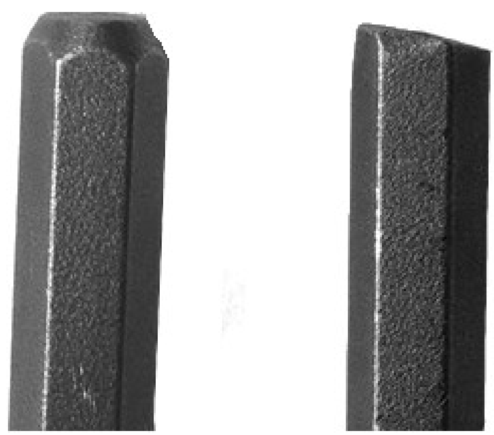

Figure 8: Example of one chisel with a level striking end and one with an unlevel striking end.

The mentioned factors combine to cause variation in the toolmarks that are created. This variation results in variation of the correlation between toolmarks. It should also be noted that many of the Set 1 outlier comparisons had T1 values over 5, still indicating a high degree of correlation but not to the degree of the majority of matching pairs.

This study demonstrates that this statistical algorithm can be applied to "pseudostriated" impression marks. While the results were good, an algorithm designed specifically for impression marks can be expected to perform better. It is hypothesized that it is effective in this scenario because the abrasive wheel imparts a regularly striated mark onto the chisel; the chisel then impresses a copy of the topography into the lead substrate. While the chisel does not create a striated toolmark by AFTE definition in the lead, the original striations caused by the abrasive wheel are regular and adequately impressed into the substrate, allowing analysis by the algorithm developed for 2D striated toolmarks.

Summary and Conclusions

Fifty sequentially manufactured chisels were used to create 500 impression toolmarks. When both sides of the chisel are considered, 1000 unique toolmarks had been created. All impressions were made by releasing a weight onto the chisel and orthogonally impressing the functional end of the chisel into a lead substrate.

Three types of algorithmic comparisons were made between toolmarks: matching pairs, nonmatching pairs from opposite sides of the same chisel, and nonmatching pairs from varying sides of sequential chisels. Three different sets of algorithmic parameters were used to analyze the data (resulting in a total of 51000 statistical comparisons). All of the parameter sets performed similarly, achieving strong separation between matching and nonmatching toolmarks. The parameter set containing 500 pixel-wide search and validation windows did achieve complete separation (excluding outliers). Numerous outliers were present in the data, primarily concentrated in the Set 1 matching toolmark data. However many of the Set 1 outliers still indicated a high degree of statistical correlation but not to the same degree as the majority of matching toolmarks. A systematic cause of the outliers was not found, but multiple factors were observed that cause variation between replicate toolmarks that could affect the degree of correlation. Some outliers may also be due to the inexact use of this algorithm to analyze impressed toolmarks.

This study demonstrates that the algorithm can successfully separate pseudostriated impression toolmarks. However an algorithm specifically designed for impression marks would likely outperform the current methods. The ability of current methods to separate matching and nonmatching impression toolmarks provides evidence and further validates the primary assumption of comparative forensic science – even sequentially manufactured tools contain unique, identifiable topographies.

Acknowledgments

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