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Objective analysis of toolmarks in forensics

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ABSTRACT

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

Objective mark comparison also extends to comparison of toolmarks made by firearms. In an effort to create objective comparisons, microstamping of firing pins and breech faces has been introduced. This process involves placing unique alphanumeric identifiers surrounded by a radial code on the surface of firing pins, which transfer to the cartridge's primer upon firing. Three different guns equipped with microstamped firing pins were used to fire 3000 cartridges. These cartridges are evaluated based on the clarity of their alphanumeric transfers and the clarity of the radial code surrounding the alphanumerics.

CHAPTER 1. BACKGROUND

A Brief History of Toolmarks

The history of toolmarks and firearms stretches back nearly 180 years to the first documented case of firearms identification in 1835 [1]. Early firearms identification relied primarily on the identification of the caliber, any macroscopic imperfections of the bullet, and the shape and type of bullet used in the crime [2]. The first recognized case of this occurred in the City of London, England in 1835. A homeowner was shot and killed, with the servant as the suspected killer. Henry Goddard, a part of the police force at the time, investigated the case and was able to identify the mold mark on the fired lead ball in addition to identifying the paper patch used in firing the black powder weapon. From these clues, Goddard was able to deduce the guilty party and bring him to justice [1].

One of the earliest cases of firearms identification in the United States occurred during the Civil War in 1863. Confederate General Stonewall Jackson was fatally wounded in battle and the bullet that killed him was used to identify the type of firearm used. It was determined the bullet could have only been fired by one of his Confederate soldiers. Union forces at that time were known to use a 58 caliber ball, while the bullet that finished Jackson was a 67 caliber ball; the same caliber used by Confederate forces. Similarly, a year later in 1864, Union General John Sedgwick was killed in battle by a single bullet. After his death, it was determined the shape and caliber of the fatal projectile were in agreement with those used in Confederate sniper rifles [1].

The late 1800s and early 1900s saw an increased interest in firearm identification. This interest included several court cases within the United States, and promoted research conducted throughout the U.S. and Europe. Published works included titles such as, “La Deformation Des Balles de Revolver” (Deformation of Revolver Bullets, 1889), “The Missile and the Weapon” (1900), “Zur Sachverstandign Beurteilung Von Geschossen” (The Expert Examination of Fired Bullets, 1905) written by A. Lacassogne of Lyon, France, Dr. Albert Llewellyn Hall of Buffalo, New York and Dr. R. Kockel of Leipzig, Germany, respectively [1]. Some credit Dr. Kockel with the first use of striation matching of toolmarks, which occurred around 1900. In his first paper, Kockel identified knife cuts made in wood through oblique lighting and photography. In a later notable paper, he described the examination of marks through magnification and measured the relative spacing with calipers. Additionally, this paper noted the change in geometry of the toolmark with different attacking angles of the knife blade [2].

In 1915, the State of New York saw a great mishandling of a murder case. Charles Stielow was accused of shooting and killing his employer and the employer's housekeeper. After being shot, the housekeeper ran and was found at Stielow's door. An alleged firearms examiner was hired to examine the evidence and determined that the revolver at Stielow's residence had fired the bullets in question. As a result, Stielow was sentenced to death. However, upon reexamination of the evidence, Charles E. Waite of the New York Attorney General's office and Dr. Max Poser of Bausch & Lomb were able to determine that Stielow's revolver was not involved in the crime in question. Stielow was subsequently pardoned. As a result of this case, Waite, Phillip O. Gravelle, John H. Fisher and Calvin H. Goddard gathered together to investigate "forensic ballistics." Consequently, the group adapted the comparison microscope to firearms identification, a vital tool still used in today's forensic laboratories [1, 2].

The next significant court case for firearms and toolmarks was the case of Paul V. Hadley in 1921. In Tucson, Arizona, Hadley accepted a ride from an elderly couple, who he later shot. The woman later died as a result of her injuries. Upon Hadley's arrest, a 32 caliber pistol and several cartridges were found on his person. A practicing attorney, A. J. Eddy, was asked to examine the bullets from the couple and determine if they were fired by the pistol carried by Hadley. Eddy performed three months of experiments and concluded that yes, the bullets had come from Hadley's pistol. As a result of Eddy's testimony, Hadley was convicted of the shootings. This ruling was appealed, only to have the lower court's ruling upheld, thereby recognizing firearms and ballistics evidence as admissible in court [1].

The 1930s, 1940s and 1950s saw continued growth of forensic toolmark and firearms analysis. By 1930 the Scientific Crime Detection Laboratory was operational at Northwestern University in Chicago, soon followed by the Federal Bureau of Identification Laboratory in 1932. Other crime laboratories popped up across the country to assist police forces in firearms and toolmark identification [1].

Most early studies and cases largely focused on ballistic toolmarks, with the exception of a few studies including Dr. Kockel's work as previously described. In 1948, Dr. Thomas of the University of Ghent added to the toolmark references by publishing a paper describing the toolmarks left on a skull by an axe. Since then, many different types of toolmarks have been characterized [2].

The Association of Firearm and Tool Mark Examiners (AFTE) was formed in 1969. Its original members were comprised of specialists from the United States and Canada. AFTE has since become an essential resource for firearm and toolmark examiners throughout the United States and abroad by providing training, access to journal articles and other resources. In 1980 the AFTE Glossary was published- complete with definitions, illustrations, formulas for bullet energies and various chemical formulas as a reference for examiners. Since then, the Glossary continues to be updated as the organization sees fit [1].

Use of Technology for Toolmark Examination

In 1958 John E. Davis wrote the book, "An Introduction to Tool Marks, Firearms and the Striagraph." In his book, Davis introduces the striagraph, a specialized instrument he describes as, "primarily a measuring, tracing and recording device suited to the analysis of micro surface-contours, that is, to the detection of microscopic irregularities in surface smoothness" [1, p.276]. Davis's methods presented a new way of objectively comparing toolmarks since the contours of a mark could be quantified. Unfortunately, Davis's work was largely ignored and the striagraph was considered primarily a research curiosity [3]. Arguably, this is the predecessor to more modern technology for recording the surfaces of bullets and toolmarks, such as laser and digital imaging used today.

Technology has greatly advanced in the past twenty to thirty years and this advancement has significantly aided the toolmark examiner. In 1999 the Bureau of Alcohol, Tobacco, Firearms and Explosives implemented the National Integrated Ballistic Information Network (NIBIN). This network enables law enforcement agencies to use 2-D digital imaging to acquire and compare the ballistics markings on bullets and cartridge cases already recorded nationwide from over 200 different sites [4]. This database utilizes the automated integrated ballistic imaging system (IBIS) to acquire digital images of markings on fired ammunition from crime scenes and compares these marks with those already registered in the database. Since NIBIN has been implemented, over 1.2 million pieces of evidence have been entered and over 47,000 hits have been recorded, greatly assisting forensic examiners with identification of ballistics evidence [4, 5].

The past nearly 180 years of toolmark identification has yielded a great body of research and reference works. Many are still as useful and relevant today as they were when first published. The basic assumption behind these works- each tool makes its own unique mark- has not changed. With the advancement of technology in recent decades, more research substantiating this idea continues to be published. Toolmark examination has remained essentially unchanged in the last half century and the ideas behind it will be discussed in the following section.

Tools and Their Marks

A tool, as defined by the Association of Firearms and Tool Mark Examiners is, "An object used to gain mechanical advantage. Also thought of as the harder of two objects which when brought into contact with each other, results in the softer one being marked" [6, p.176]. Tools can be thought of as typical instruments such as a screwdriver, hammer, pry bar, drill bit, punch, or possibly something else, such as a car bumper or a rock. From this definition, tools can be a wide variety of objects and create any number of different marks, though each mark is thought to be unique to the tool that made it.

Tools and their marks are significantly affected by the manufacturing processes used in production. For this reason, examiners are expected to be familiar with various manufacturing processes such as forging, casting, machining, extrusion, etc. Some manufacturing processes produce marks that evolve over time as a result of the cutting tool in contact with the workpiece, such as broaching or machining. The wear on the cutting tool's surface is well documented [7, 8], especially in a machining operation. A built up edge can occur during machining, especially if a ductile material is cut slowly. This built up edge occurs when the material begins to cold weld onto the cutting edge of the tool due to the high pressures associated with the process. As the material builds up, it breaks off and new material begins to replace the previous built up edge. This ever changing cutting edge is reflected in the finished surface of the work piece. In the case of tools, this subtle change in the cutting surface has been used to examine sequentially manufactured tools and their marks [7, 8].

In addition to manufacturing, toolmarks are also affected by circumstances and the environment after the tools' production such as tool wear or corrosion. The working surface of a new tool will change rapidly during its initial use until the "break-in period" is over. Wear rate then slows and becomes more uniform. Furthermore, tool misuse and abuse will result in a more unique working surface and therefore a more unique toolmark. This change in working surface due to wear can greatly assist an examiner when determining the tool used in a crime [8].

Toolmark Characteristics

Different types of tools leave different types of marks. The two main types of marks are impressed marks, such as a hammer strike, and striated marks, such as those made as a screwdriver slides across a softer surface [6]. These two types of marks can be found together at times. For example, firearms produce impressed marks on the cartridge primer when the firing pin strikes it and striated marks on a bullet as it passes through the rifled barrel.

In addition to the broad classifications of impressed and striated marks, toolmarks are also characterized by individual, class and subclass characteristics. Individual characteristics are random imperfections, which are produced during manufacture or caused by use, corrosion, or damage [6]. Individual characteristics are what make a tool unique amongst other tools of its type and are produced by accident. An example of an individual characteristic might be a screwdriver that has a chip missing from one edge of the blade. Marks then made from this edge will have an individual characteristic that separates them from other screwdriver marks.

Class characteristics are features determined prior to manufacture; this includes size and shape of the tool. Examples of these characteristics might be the caliber of a firearm or size of a hammer's head. Also included in class characteristics is the type of action imparted by the tool: compression, crimping, shearing, slicing, etc. [6, 8].

Subclass characteristics are somewhat less clear and more elusive than individual or class characteristics. They can be mistaken for individual characteristics, though trained examiners are able to distinguish between the two. Subclass characteristics, as defined by AFTE are, "discernible surface features of an object which are more restrictive than class characteristics in that they are produced incidental to manufacture; are significant in that they relate to a smaller group source (a subset of the class to which they belong); can arise from a source which changes over time" [6, p.175]. Examples of these marks include broaching marks or mold marks on a part from a master pattern. With the case of broaching marks, due to the contact of the cutting surface with the workpiece during manufacture, the cutting tool is constantly undergoing change due to abrasion and built up edge, as previously discussed. This changing cutting surface is reflected in the workpiece after the broaching operation is complete [8].

Toolmark Comparison Techniques

The objective of a toolmark examination is to determine if a suspect tool made an evidence mark. Generally speaking, the comparison of tools and their marks can be classified into two general categories: pattern fit and pattern transfer. Pattern fit is easily understood and can be likened to a puzzle piece fitting into the missing part of a jigsaw puzzle. Each piece of the puzzle is assumed to be unique and fit only in its designated place. Pattern fit can also be described as a physical match or a fracture match. The more contours the fractured surfaces possess, the higher the likelihood of a true match. For example, if a ceramic mug is accidentally dropped and breaks, the shards can be pieced back together. On the other hand, pattern transfer is not quite as straightforward because it involves impressions and striations of two and three dimensional marks. Consider a screwdriver blade sliding across a lead surface. The blade of the screwdriver has its own contours and when the action is performed with adequate force, it will leave a striated mark with the transferred pattern of the blade on the lead. Hammer impressions, striated chisel marks and the firing pin impression upon a cartridge primer can all be grouped into the pattern transfer category [9].

Because pattern transfer encompasses such a wide variety of markings, it is the primary focus of discussion during the examiner’s work and training .When a suspect tool and evidence mark are submitted for evaluation, the examiner will study the tool and mark in question to determine if the mark was made by a tool with class characteristics similar to the tool submitted. If so, then the examination continues and the tool and evidence mark are evaluated for any trace evidence such as paint or metal transfer. Test toolmarks are made with the suspect tool with the intent to recreate the evidence mark as closely as possible. This includes accounting for the angle of tilt and angle of progression used to create the original mark. The test marks are then examined with a comparison microscope to see if in fact an identification exists between the tool in question and the given evidence mark. An identification is determined when 'sufficient agreement' exists between the test toolmarks and the evidence mark [8]. The definition of 'sufficient agreement' will be further discussed in the next section. Once a toolmark identification is made, four different statements are expected to be true: 1) the suspect tool was used to make the evidence mark, 2) the tool's working surface has not been significantly damaged since making the evidence mark, 3) the evidence mark has sufficient unique features for comparison, and 4) the tool's working surface has an individual surface finish [9].

Theory of Toolmark Identification

When evidence marks are submitted for examination, a toolmark examiner is presented with four possible conclusions when evaluating the marks: identification, inconclusive, elimination, or unsuitable. These four categories are fairly self-explanatory. Examiners often err on the side of caution and only accept identification when there is overwhelming support for this conclusion.

The Association of Firearms and Toolmark Examiners has accepted a non-quantitative position on the theory of identification of toolmarks. AFTE's theory simply states, "The theory of identification as it pertains to the comparison of toolmarks enables opinions of common origin to be made when the unique surface contours of two toolmarks are in "sufficient agreement"" [6, p. 175].

This qualification of sufficient agreement is somewhat vague; however AFTE does provide clarification for this term. Agreement between marks is significant when it "exceeds the best agreement demonstrated between toolmarks known to have been produced by different tools and is consistent with agreement demonstrated by toolmarks known to have been produced by the same tool" [6, p. 175]. By concluding two marks have sufficient agreement, examiners acknowledge that the likelihood of another tool making these marks is so remote as to be considered a practical impossibility [6]. Because toolmark examinations and, ultimately, the conclusion of "sufficient agreement" are subjective in nature, this method has received considerable criticism [10, 11]. While AFTE acknowledges this subjectivity, it does state that the interpretation of identification is founded on scientific principle and, in the end, is based on an examiner's training and experience [6].

Consecutive Matching Striae

The traditional method of identifying toolmarks is pattern matching. However, in an attempt to quantify a "match," a method of counting the consecutively matching striae (CMS) has been suggested. Both pattern matching and CMS employ the same science and techniques, but differ in the manner in which they describe their results. Nichols acknowledges this by saying, "There is no difference between a "pattern matcher" and a "line counter" except the manner in which they document their casework and articulate their conclusions" [12, p. 300]. The CMS method will describe the best non-match observed and from that experience an examiner can use this information to determine an identification. Nichols argues, especially in court CMS, appears to hold up better than the traditional pattern matching, since the CMS method is better able to articulate the reasoning for an identification in a way that a lay person might understand the result.

The Daubert Criteria

In 1993, the case of *Daubert v. Merrell Dow Pharmaceuticals, Inc.* changed the admissibility standards of expert testimony. Previously, the case of *Frye* in 1923 had been the accepted standard. Under *Frye*, the only criterion set forth for the admissibility of expert testimony was that the opinions expressed by the expert had general acceptance in the field in which it belongs. By being accepted by its respective field, the testimony was believed to have been thoroughly tested and thus be valid in court. The *Frye* test held until 1993 when *Daubert* sought to define in more specific terms the *Frye* principles associated with the description of being "thoroughly tested" by outlining a set of criteria for expert witness testimony. Under *Daubert*, four different criteria must now be met: 1) testability of scientific principle, 2) known or potential error rate, 3) peer review and publication, and 4) general acceptance in a particular scientific community. Through these criteria, *Daubert* has essentially placed the presiding judges into gatekeeper positions, leaving them to decide what is admissible and what is not. While *Daubert* is now the controlling standard for all federal cases, not all states have adopted it and many still use *Frye* or some modification of it when evaluating admissibility [13].

Toolmark examination can and does meet the criteria set forth by *Daubert*, but many attorneys have sought to have the examiner's testimony omitted from cases claiming the examinations are not rooted solidly in science or that the examiner's conclusions are subjective and cannot be trusted [13, 14]. A scientific foundation and objectivity are found in any experienced toolmark examiner's toolmark comparisons. In recent years, to reinforce these ideas, different groups have sought to make objective toolmark comparisons with the use of comparative statistical algorithms.

Research Related to Toolmarks

Toolmark research, as it relates to tools, clearly has a long history extending to the turn of the twentieth century with the publication of Dr. Kockel's papers. In 1942 a notable paper was published by Burd and Kirk examining the marks made by screwdrivers. In this study [15] the authors addressed four different points: 1) the effect of varying the angle of application of the screwdriver on a toolmark, 2) establishing the necessary criteria for identification, 3) assessing the similarity between tools with identical appearance and manufacturing process, and 4) classifying the different types of marks that can be encountered. Burd and Kirk pointed out in the study the traditional method of examining toolmarks with oblique lighting and a comparison microscope will only yield a match if, and only if, the marks in question have a similar contour, since this is reflected in the "lines" or striations seen through the microscope. The authors go on to conclude several important points. First, two marks made with the same tool must be made with a difference in vertical angle of no more than 15 degrees if a match is to be obtained. Similarly, two marks made with the same tool must be made with a difference in horizontal angle of no more than 20 degrees if a match is to be determined. The authors also established the maximum percentage of lines that matched in non-match comparisons did not exceed 25% and when match comparisons were performed this percentage jumped to around 80%. Additionally, examination of "identical" tools produced noticeably unique marks that could not be matched to another "identical" tool. This paper is very well written and remains valuable and relevant today.

As summarized by Nichols [16], many other papers have been published by various authors concerning toolmarks made by other tools since Burd and Kirk's study. Several studies have since been published concerning toolmarks made by screwdrivers, as they make the quintessential striated mark that is easily examined. Nichols specifically mentions those published by Burd and Gilmore [17] and by Vandiver [18]. Other significant studies concerning knives [19, 20], bolt cutters [21-23], drill bits [24], rotary glass cutters [25] and cast bullets [26] all reach the same conclusion, namely, each tool makes its own unique mark.

Tongue and groove pliers were evaluated in 1980 by Cassidy [27]. These pliers are often used to pry open door handles and their marks are simple striated marks stemming from a plier tooth sliding across a surface gripped in the pliers' jaws. For this study Cassidy procured three sets of upper and lower jaws that were sequentially broached with no further manufacturing processes applied to preserve any subclass characteristics present from the broaching process. He observed no subclass characteristics that might be mistaken for individual characteristics. In the study's discussion, Cassidy demonstrates that the pliers' teeth were broached perpendicular to the direction that the marks are made and would not produce any subclass characteristics in the striated marks. Furthermore, actual tongue and groove pliers in production go through many processes after broaching; thus, marks produced by these mass production pliers would produce only marks that have individual characteristics.

With the availability of inexpensive computing power and increasingly precise metrology instruments, toolmarks are being reexamined through objective statistical comparison of their 3-D profiles. In 2007 Faden et al. [28] developed a computer algorithm to compare and match surface data taken from a stylus profilometer. In the study, 44 sequentially manufactured screwdriver tips were used to create marks at 30, 60 and 85 degrees from both sides of the screwdriver blade and the profilometer used to record the surface contours of the mark through 9600 data points. A computer program was then used to compare the collected profilometer traces. Three different comparison data sets were generated: 1) true matches, 2) true non-matches, and 3) comparisons between side A and side B of the screwdriver blades. The Pearson correlation was calculated for all comparisons. Faden et al. determined that while there is a significant separation in the correlation values between true match and true non-match marks at the same angle, the Pearson correlation is not effective at determining when an actual match exists. Moreover, marks made from different sides of the same screwdriver tip produced a separation of data consistent with that of non-matches.

In 2010 Bachrach et al. [29] expanded the research of statistical comparison of toolmarks by evaluating screwdriver marks, and tongue and groove plier marks through confocal microscopy. In this study, Bachrach et al. examined marks made by screwdrivers at different angles in lead and aluminum. In addition, they examined the marks from tongue and groove plier marks in lead, brass and galvanized steel. After scanning the marks with a confocal microscope, the mark data were normalized to level the data, and then put through a signature generation process. This process took the cross sectional profile of the mark and applied a Gaussian band pass filter to eliminate class characteristics within the mark. Then, two signatures were run through a correlation component to evaluate the two signatures' similarity to each other. From this study, several conclusions were drawn. First, striated toolmarks in the same medium and produced under the same conditions are repeatable and sufficiently specific to allow identification. Second, striated toolmarks created with the same conditions, but different media, have a high reproducibility. Third, screwdriver marks depend on the angle at which they are made more than the media in which they are created. Fourth, the probability of two tools displaying similar features is extremely small. Finally, the probability of error originated from a poor toolmark image, not from the tool's failure to create an individual toolmark.

Chumbley et al. [30] continued with the work performed by Faden et al. in 2010. In this study, a statistical algorithm was used to evaluate its effectiveness in comparison to actual toolmark examiners. Again, data were collected by a stylus profilometer for 50 sequentially manufactured screwdriver tips. Marks were made at 30, 60, and 85 degrees for both sides of the screwdriver tip, A and B. The mark profiles collected were then analyzed by a statistical algorithm. These calculated results were then compared to a double blind study where 50 experienced toolmark examiners evaluated a given sample set with which the algorithm had difficulty. The results from this study showed that while the objective algorithm was very effective in discriminating between known matches and known non-matches, it still did not reach the level of performance of experienced examiners.

Objective statistical comparison continued through research done by Petraco et al. in 2012 [31]. In research supported by the U.S. Department of Justice, Petraco evaluated striated marks from screwdrivers and chisels, as well as striated and compressed marks from cartridge cases. Like Bachrach et al., Petraco et al. also used confocal microscopy when collecting the surface profiles of the sample marks. The results of this study showed chisel marks were patchy at best and proved too complicated for the developed software to analyze successfully. Screwdriver and cartridge cases had much more success in comparisons and had very low error rates. With the successes and the difficulties associated with this current software, Petraco et al. have made their marks and software open sourced and accessible to others in the forensic community.

Statistical Algorithm for Toolmark Analysis

Since the algorithm developed by Faden et. al. and Chumbley et. al. forms the basis for part of the analysis conducted in this thesis, it is suitable to provide a brief description. The algorithm used divides analysis into two distinct operations: Optimization and Validation. In the first step, Optimization, the algorithm seeks to identify a region of best agreement between the two chosen datasets for a user defined window size, the red boxes in Figure 1. This is achieved by calculating the maximum correlation statistic, described in an earlier paper [28]; this is also referred to as the "R-value." Values very close to 1 indicate regions of the datasets which are very similar. As previously indicated [30], Optimization is not the best tool to use when determining matches and non-matches. For this reason, the algorithm employs the comparison process called Validation after the Optimization process. In this step, a series of windows of are randomly chosen and shifted common distances from the regions defined as areas of best fit, the purple boxes in Figure 1a. The R-value for these areas is then calculated and many other rigid window shifts are performed. The idea behind the random rigid window shift is if a true match exists, there is reason to believe that many rigid shift window comparisons will yield larger R-values. Conversely, if a true match does not exist there is no reason to believe that rigid shift comparisons over the length of the mark will yield large R-values. It should be noted the R-values in this step are assumed to be lower than the one defined by the Optimization step, as that was the highest R-value for the two datasets. The next step in Validation calculates R-values at random locations along the length of the datasets, Figure 2. The random window shifts are expected to have lower R-values than the rigid window shifts. In the case of a non-match, the rigid window shifts and the random window shifts in the Validation step will have similar low R-values. To conclude the algorithm's process, a Mann-Whitney U-statistic is computed to join all of the comparisons together. This statistic is referred to as a T1 value. T1 values close to zero indicate the case of a non-match, while higher T1 values indicate the case of a match.

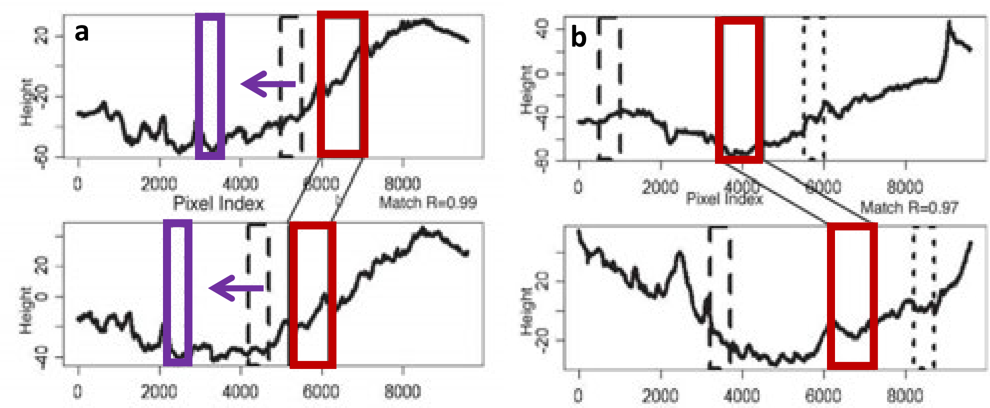

Figure 1: a) Line profiles of known match comparisons. b) Line profiles of known non-match comparisons.

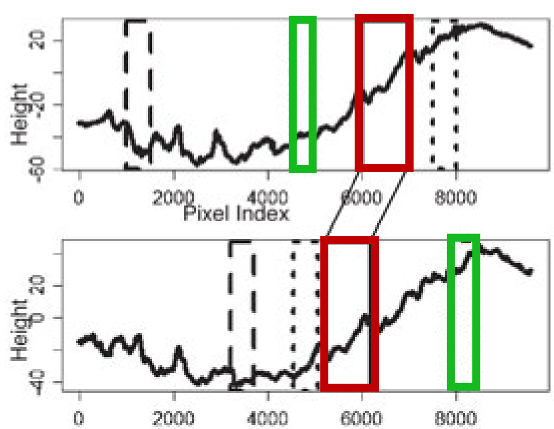

Figure 2: Random shift windows, green boxes. Red boxes indicate region of best agreement found during the Optimization step.

This algorithm is subject to current and future work involving the comparison of striated and quasi-striated marks such as shear marks from slip joint pliers, which will be discussed later in this thesis.

Research Related to Firearms

In 1959 Biasotti published an extensive statistical evaluation of the individuality of bullets fired from different firearms [32]. Thus far, this remains the most exhaustive statistical empirical study ever published for firearms examination. Biasotti used twenty four .38 Special Smith and Wesson revolvers: 16 used and eight new guns. He compared the land and groove impressions from bullets fired from the study's guns and in doing so created a new way to describe striated markings, consecutiveness. This arguably was the beginning of the CMS method as a way to describe striae.

Numerous studies have been done relating to firearms in the last century of forensics work. Nichols [16] provides excellent summaries of many of the more notable studies for bullets, gun barrels, and cartridge cases. Included in his review are several studies examining the marks imparted on bullets from rifled barrels, a study on the individuality of button rifled barrels, a study examining sequentially manufactured firing pins, and several studies concerning breech face markings. Traditionally, all of these factors-bullets, gun barrels, cartridge cases, and firing pins- are evaluated by an examiner when presented with firearm evidence. However, the numerous studies concerning the individuality of each gun and its respective working surfaces have not deterred attorneys from attempting to throw out ballistics evidence [14].

In an effort to eliminate the arguments of subjectivity in ballistics examination, the idea of microstamping was conceived by Todd Lizotte and Orest Ohar in 1994 [33]. Microstamping involves placing unique, identifiable characters on the end of a firing pin or breech face of a gun. When fired, the microstamp impresses the unique identifiers onto the fired cartridge case with the intention of making identification of the firearm relatively straightforward; something an officer on a crime scene could identify with a hand lens. The creators' other intent with the introduction of this technology was to make it possible to track patterns of gun crimes. If cartridge cases are left at the scene of several crimes that trace back to the same gun, a pattern can emerge which could be helpful for law enforcement [34].

Current microstamped marks have six to eight alphanumeric characters surrounded by a gear code placed on the end of a firing pin, Figure 3. The alphanumeric marks are intended to act similar to the way a license plate acts to identify a car where each code can be traced back to a specific firearm. The gear code surrounding the alphanumerics is intended as a backup, i.e., it provides a way to identify the cartridge in the event the alphanumeric identifiers cannot be read. It acts somewhat like a barcode, as it is read in six-bit binary in zeros and ones. The gear code, outlined in Figure 3, is divided into eight equal sectors of 42 degrees with a starting wedge of 24 degrees at the top of the mark. These eight sectors, read clockwise, correspond to each alphanumeric identifier as it is read left to right. The first sector of the gear code corresponds to the first alphanumeric, S, the second sector to 2, etc. Within each sector there are 7 degree increments, which correspond to the aforementioned ones and zeros. For example, the first sector reads 011001, which corresponds to the letter S. The entire gear code in Figure 3 can be translated to read S23-SX7-SS.

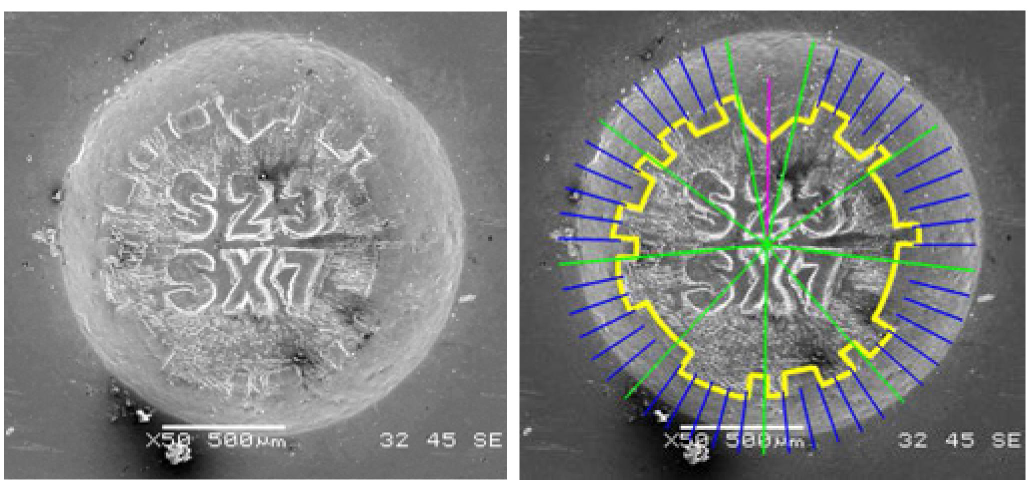

Figure 3: a) Microstamp of Sig Sauer cartridge, b) microstamp of Sig Sauer cartridge with overlay

Needless to say, the introduction of this idea and technology has largely polarized lawmakers and the public. Those critical of guns and gun law have pushed for legislation requiring all guns to have a microstamped firing pin. On the other side, pro-gun advocates vehemently reject any requirements to have such regulations applied to guns while manufacturers claim that implementing such technology will raise costs and force many companies out of business [35].

Despite microstamping being a hot button issue with gun lovers and gun haters, a fair amount of research has been performed to evaluate the reliability of the transfer and the durability of the microstamp. Perhaps the most extensive study performed occurred at the University of California, Davis [36]. This study was very extensive and encompassed many different aspects of microstamping including the durability and longevity of characters, their legibility, obliteration, the costs associated with implementation along with extensive appendices containing all the data. This study is extensive and several key points should be considered. First, the quality of transfer is heavily dependent on the firearm, and can also be affected by the ammunition used. Some flattening and degradation of the alphanumerics were seen throughout the study. Additionally, the radial bar code structure showed severe wear, though it should be noted that since this study the gear code structure has been revised to produce a more discernible mark [34]. Finally, destroying the microstamp was very easily accomplished when the firing pin was removed from the weapon.

It remains to be seen if microstamping will gain widespread legislation throughout the United States. However, further research into the durability and transfer of microstamping is necessary to come to definitive conclusions before legislation is passed requiring this technology. For this reason, an examination of microstamping is also undertaken in this thesis and the results are discussed in later chapters.

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CHAPTER 2. OBJECTIVE COMPARISON OF MARKS FROM SLIP-JOINT PLIERS

A paper to be submitted to the *Association of Firearm and Tool Mark Examiners Journal*

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Introduction

In the last twenty years, several different court cases, including perhaps the most well-known, *Daubert v. Merrell Dow Pharmaeuticals, Inc.,* have called into question the validity of scientific testimony, especially as it relates to firearm and toolmark examination. As a result, recent research has sought to justify a basic assumption made by forensic examiners: each tool makes its own unique mark. Many different tools and their marks have been examined in the research setting including screwdrivers [1-4], tongue and groove pliers [4, 5], and chisels [3].

Striated screwdriver marks have been well studied and characterized by stylus profilometry and confocal microscopy. These characterizations have been used to analyze potential matches and non-matches via statistical validation in several different studies [1-4]. In general the results have shown that striated marks can be compared objectively using computer algorithms with a fairly high success rate. Studies of somewhat irregular marks also exist, although to a lesser extent. Cassidy first published a study on the examination of toolmarks from sequentially manufactured tongue and groove pliers, as they are frequently used to twist off doorknobs to break into buildings [5]. This study, while not based in statistical validation, did establish that the tongue and groove pliers only produce individual characteristics due to the teeth being broached perpendicular to the direction of the striated mark. Bachrach et al. more recently examined the marks produced by the application of tongue and groove pliers to different materials (lead, brass and galvanized steel) and used statistical comparisons to objectively compare the marks [4]. Bachrach et al. found the tongue and groove pliers marks could readily be compared when made on the same media. However, the empirical error rate increased when comparing marks made on different media. Chisel marks have been evaluated by Petraco et al. [3], but the patchy striated chisel marks used in this research proved too difficult for the developed suite of software currently in use to provide useful information during comparison. Thus, while a small body of work exists on less than perfectly striated marks, the results are somewhat disappointing at this time.

In a previous study [2], fifty sequentially manufactured screwdriver tips and their marks made at different angles were examined and compared though a statistical algorithm to determine the strength of evidence of a positive match between a mark and the tool that made it. This algorithm has been used extensively to evaluate the evenly striated marks of screwdrivers, however it has not yet been used to evaluate less striated marks or impression marks. As a first step toward investigating the applicability of the current algorithm, quasi-striated marks such as those made by slip joint pliers when cutting wire were examined. Slip joint pliers were chosen since no studies currently exist on this subject to the authors' knowledge. Additionally, they were expected to produce a more difficult mark for analysis, due to the manner in which cutting occurs. When cutting a wire with slip joint pliers, the mark produced reflects both striations from the actual cutting and smearing, due to shearing of the material during the process. This results in a mark that is not continuous from the beginning of the cut to the end. Thus, the surface topography that exists at the initial cut edge of the mark could vary substantially from what is seen at the final cut edge.

Experimental

For this experiment, 50 pairs of sequentially manufactured slip joint pliers were purchased from Wilde Tool Co., Inc. so as to be as nearly identical as possible. It is well known the manufacturing process greatly affects the resulting toolmarks a tool makes due to the surface features imparted on the tool during manufacturing [6, 7]. For this reason, a detailed description of the way the pliers used in this study were manufactured is in order.

All of the plier-half blanks examined in this study were hot forged from the same die, followed by cold forging from the same forging die. Following forging, holes were punched to seat the fastener, i.e. the bolt that will hold the two halves of the pliers together. At this point a difference is introduced in the blanks. On slip joint pliers, one half of the pliers has a small hole, while the other half has a larger, double hole allowing the user to gain a better grip when using the pliers (see Figure 1). Once the plier holes were punched the teeth and shear cutting surfaces were created using a broaching process. It is this machining method that creates the scratch minutiae on the surface of the plier halves responsible for producing the characteristic toolmark that is of interest in forensic examinations.

Figure 1: Slip joint pliers in their unfinished and finished states. From left to right: plier halves (single and double hole) before broaching; an example flat side of pliers that will be polished; finished and labeled pliers (sides A and B).

The plier halves for this study were cut on two separate broaching machines; halves with the smaller hole were all broached on one machine, while the halves with the double hole were broached on a second. At this point in the process the manufacturer stamped numbers 1-50 on each plier half as they were finished being broached. Thus, the 50 pairs could be assembled with confidence that they were actually made sequentially. After broaching, both halves were given the same heat treatment and shot peened to surface harden the metal. The long, flat surface was then polished and the pliers were assembled and gripped. As a final step the company branded the double hole side of each pair of pliers. For the purposes of this study each half of the pliers was assigned as either A or B, with Side B being the branded half of the pliers (see Figure 1).

To make the samples, copper wire of 0.1620” diameter and lead wire of 0.1875” diameter were obtained and cut into two-inch lengths with bolt cutters to distinguish the ends from the cuts made by the pliers. Next, the cut lengths of wire were placed centered in the plier jaws on the cutting surface with pliers side B facing down. Alternating shear cuts of lead and copper were made with each pair of pliers for a total of 21 cuts. All odd numbered cuts were lead samples; all even numbered cuts were copper. The total number of copper samples thus obtained was 1000, with 500 cuts in contact with Side A, 500 cuts with side B.

For the purpose of this study, only the copper samples were evaluated. Each cut mark surface was scanned optically with an Alicona Infinite Focus G3 profilometer at 10x magnification to acquire the surface geometry of the mark. An example of a typical scan is shown in Figure 2. The tool mark is seen to be quasi-striated, i.e. parallel linear striae do exist but it clearly varies across the surface of the cut mark.

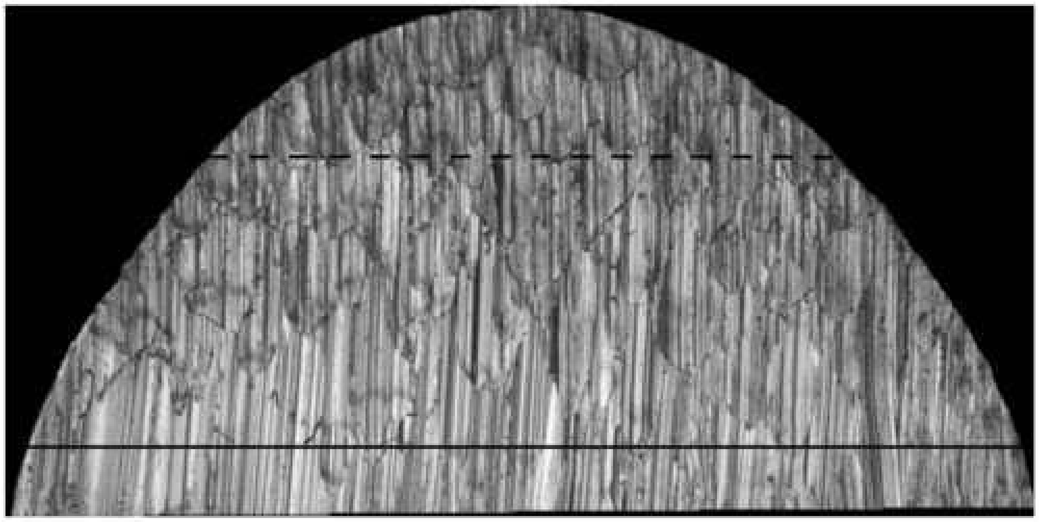


Figure 2: Areas examined during comparisons. Dashed line is referred to as the "short edge," the solid line is referred to as the "long edge."

When the data are acquired, noise spikes occur around the edges of the mark where the cut surface drops off because there is no surface here for the profilometer to scan. This noise is non-informative for the matching process, and is not desirable in the data file. Therefore, the raw data are processed using a computer routine to remove the extraneous noise spikes. This process is referred to as a cleaning routine and does not affect the data that characterizes the cut surface. An example of a clean and uncleaned data file can be seen in Figure 3.

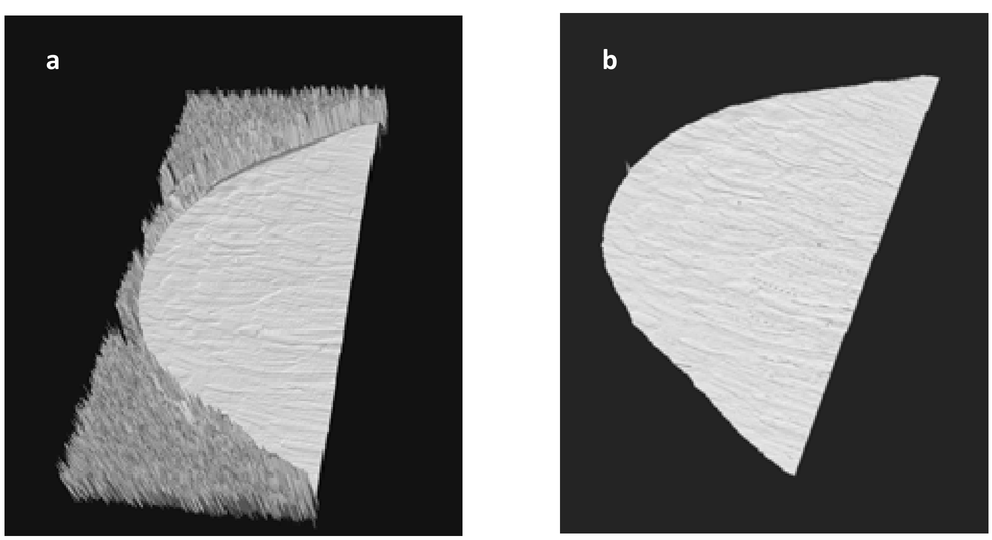


Figure 3: a) Raw data; b) cleaned data with noise spikes removed

All raw data files contained trended data. Simply put, due to the manner in which the data were collected the line profile of a mark data file had an increasing linear trend in the z direction moving from one side of the mark to the other. Such a trend is common when using profilometers since the surface analyzed is rarely exactly parallel with the direction of scanning. Because the files were a rectangular collection of 3D data (shown in the uncleaned data of Figure 3a), trending was corrected by subtracting a plane matching that of the trended data from the file. To accomplish this, the detrending routine selects left and right diagonal points from the data (approximately 40 on each side, 80 in total) and uses a linear least squares method to fit the appropriate plane for the data. It then subtracts the fitted plane from the data to achieve an appropiately leveled data file for comparison. As a reference, these final data files are roughly 2200 by 4500 pixels.

Comparisons between the marks were made using the previously described algorithm [2]. The comparisons were divided into two different groups, those made close to the end of the mark, as designated by the solid line in Figure 2, and those made close to the start of the mark, shown by the dashed line in Figure 2. From this point on, the dashed line data will be referred to as the short edge and the solid line data as the long edge. These mark locations were chosen to examine differences between the beginning of the cut, where the mark has short and variable length striae, and the end of the mark, where the striae are longer and appear to be more regular.

Each side of the pliers was considered to be a separate data set, the assumption being, as confirmed by forensic examiners, each side acts as a different surface. Given there are 50 pairs of pliers, with two sides for each pair of pliers and ten replicate cuts for each side of each pair of pliers, the total number of samples possible for examination came to 1,000 discrete data sets.

Results

A sampling format was set up to compare three different groups of data: known matches, known non-matches from the same pair of pliers (i.e. different sides), and known non-matches from different pairs of pliers. The comparison setups are as follows:

Set 1: Compare known matches. These should be marks from the same side of pliers. Comparisons were made between marks 2 and 4 and between marks 6 and 8 for each side of the pliers, side A and side B.

Set 2: Compare known non-matches from the same pair of pliers. Comparisons were made between side A and side B for marks 10, 12 and 14.

Set 3: Compare known non-matches from different pairs of pliers. The samples were divided into 12 groups of four, each numbered consecutively, e.g. tools 1-4, 5-8, etc. Comparisons were made for both side A and side B. Table I shows an example comparison setup for the first group of pliers.

Table I: Comparisons for Set 3, Group 1

Comparison	Plier number	Side	Mark number	Plier number	Side	Mark number
A	1	A	16	2	A	16
B	3	A	16	4	A	16
C	1	A	18	4	A	18
D	2	A	18	3	A	18
E	1	A	20	3	A	20
F	2	A	20	4	A	20

The same algorithm used in an earlier work for striated marks [2] was applied in this study to examine the quasi-striated marks made by the slip joint pliers. The algorithm has two primary steps: Optimization and Validation. During the Optimization step, the regions of best agreement between the two marks are determined by the maximum correlation statistic, or “R-value.” The size of the region is assigned by the user and is hereafter referred to as the “Search Window.” The second step of the algorithm, Validation, uses both rigid and random window shifts to verify the regions chosen in the Optimization step indeed correspond to a true match. These windows are hereafter referred to as the “Valid Windows” and their width is also user determined. The R-values in this step must clearly be lower than the R-value in the Optimization step, as the highest R-value has already been calculated. However, in the instance where a true match exists, the R-values associated with the rigid shift valid windows should be larger than those associated with the random shift valid windows, the assumption being, if an excellent match exists at one location then very good matches should exist at any number of corresponding locations. If true, this is indicative a true match does exist. Conversely, rigid window shifts do not produce systematically larger R-values than random shifts in the case of a true non-match, since the high values found during the Optimization step exists due to random chance rather than any physical relationship between the items being compared. Further discussion of this algorithm can be found in the literature [2].

Originally, the size of the search and valid windows were set at the comparison software’s default 200 and 100 pixels, respectively, and the comparisons were conducted with samples from the first 20 pairs of pliers. This setup produced 400 different comparisons for the long and short edge comparisons. When a comparison is made, indication of a true match is found when the T1 value of the statistic returned is relatively high. Little or no relationship between the marks results in T1 values centered near 0.

Results of these early comparisons can be found in Figure 4. In these box plots, the bold line in the middle of the box represents the median, the lower quartile by the bottom line of the box, and the upper quartile by the top line of the box. The whiskers are one and a half times the difference between the upper and lower quartiles. Any outliers outside the whiskers are denoted by dots. In these plots, known matches are in the comparisons designated Set 1, while Sets 2 and 3 show comparisons between known non-matches from different sides of a pair of pliers and non-matches between different pairs of pliers, respectively. It is evident that with these window sizes, the success of identifying known matches was relatively low, there being little separation between the returned T1 values of known matches and non-matches.

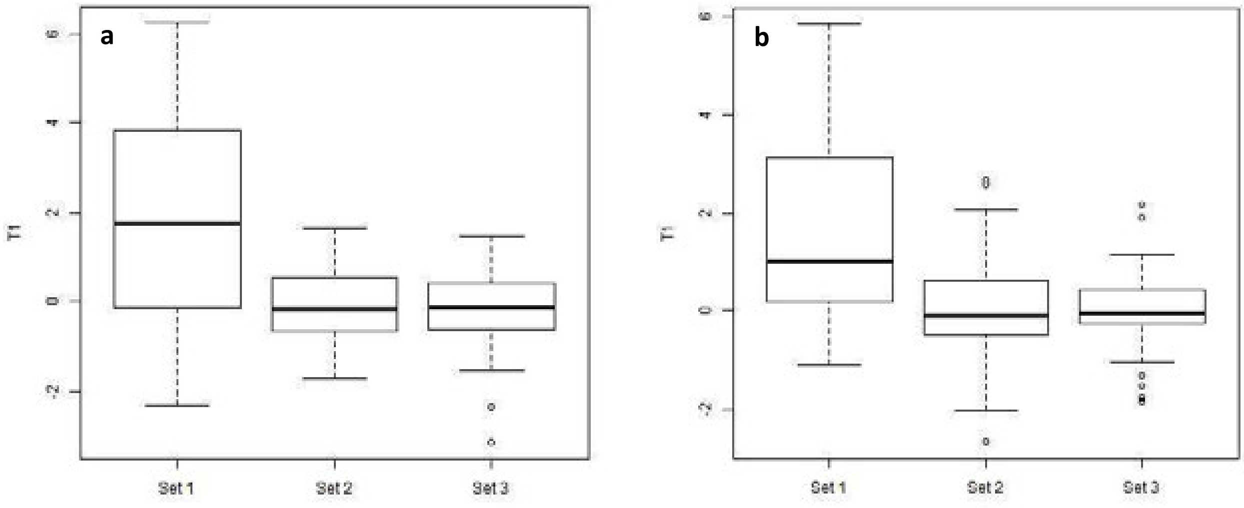


Figure 4: Original data comparisons for (a) short edge, (b) long edge.

From the minimal success of the first attempt at matching the plier marks, several changes were decided upon for further comparisons. First, the data shown in Figure 4 compared trended data. This was corrected in subsequent comparisons. Second, it was decided to vary the window size for all plier mark samples. The initial values used were chosen simply because they had proven effective for comparison of fully striated marks. A series of experiments was conducted within each plier comparison set where the window sizes were varied to evaluate the effect window size has on the resulting T1 value. In other words, the question asked was: does the size of the window play a large role in the discrimination between known matches or known non-matches? In this series of experiments Search and Valid windows were assigned four different values. The Valid window was always half the size of the Search window. Search windows were set at values 100, 200, 500, and 1000 pixels, respectively, to examine the effects of one smaller Search window and two larger Search windows. These new settings were extended to all 50 pairs of pliers and their corresponding toolmarks in the copper wire, bringing the total number of comparisons to 3,952.

The results of these comparisons can be found in Figures 5 and 6. Observation shows that the T1 value increases dramatically with increasing window size. While known non-matches return values centered around zero regardless of window size, the T1 value for known matches increases from just slightly over zero to an average of 6.36 and 6.09 for the largest window size for the long and short comparisons, respectively. However, the data range increases as well. At the larger window sizes, numerous outliers exist and failure of the algorithm occurs in some cases, especially for the short edge comparisons.

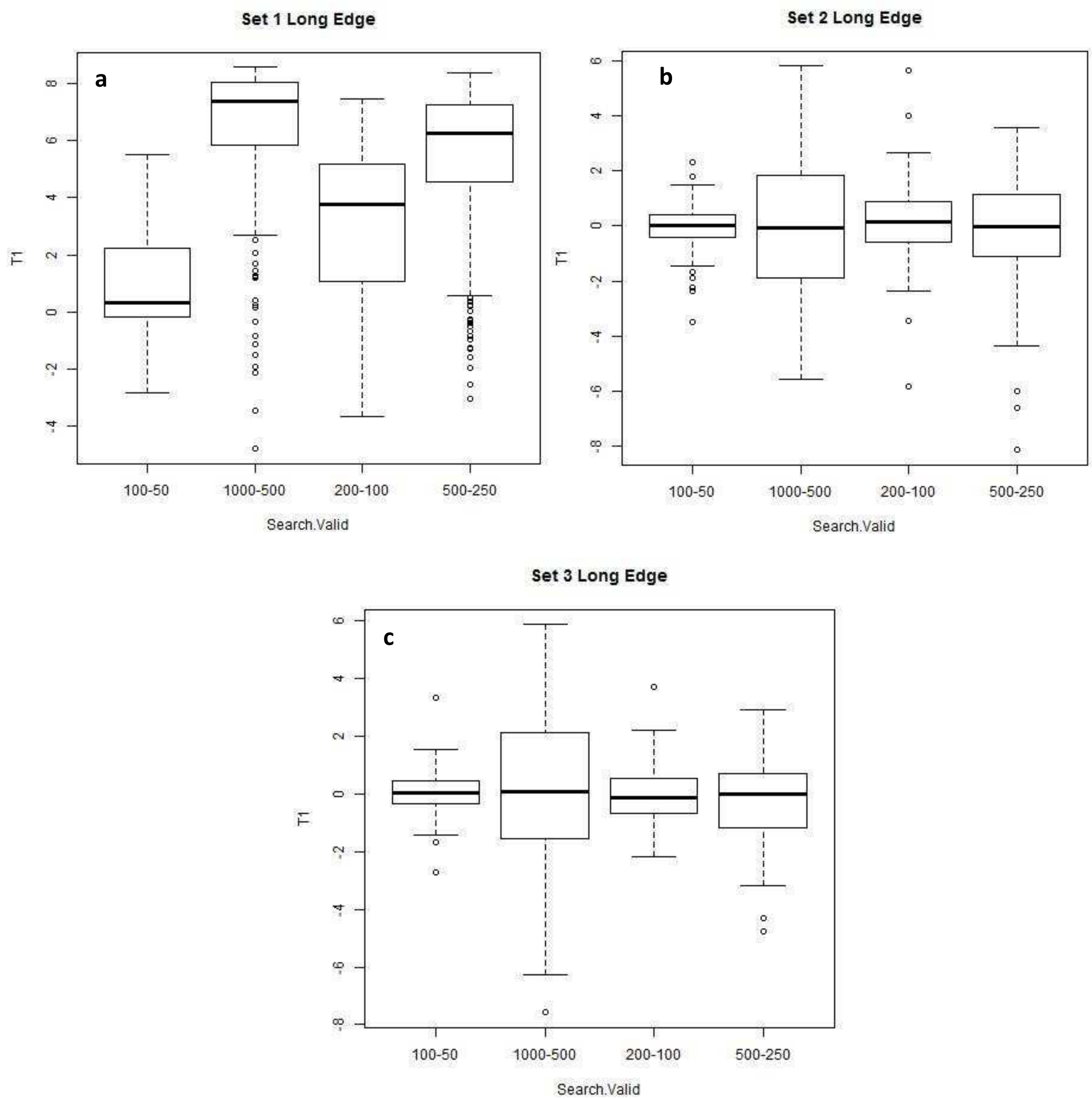


Figure 5: Long edge comparisons. a) Known matches from the same set of pliers. b) Known non-matches from the same set of pliers. c) Known non-matches from different sets of pliers.

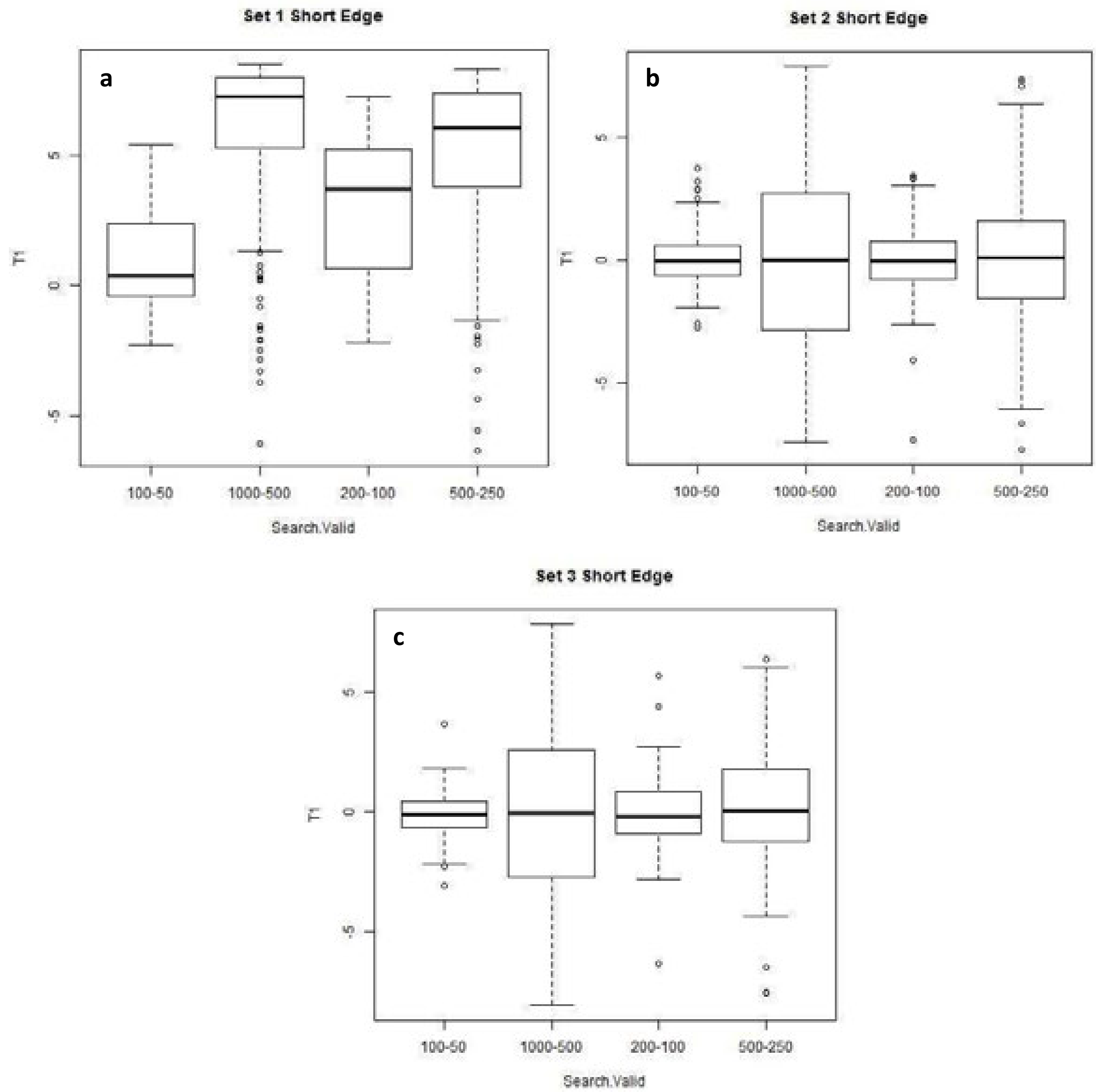


Figure 6: Short edge comparisons. a) Set 1: Known matches from the same set of pliers. b) Set 2: Known non-matches from the same pair of pliers. c) Set 3: Known non-matches from different pairs of pliers.

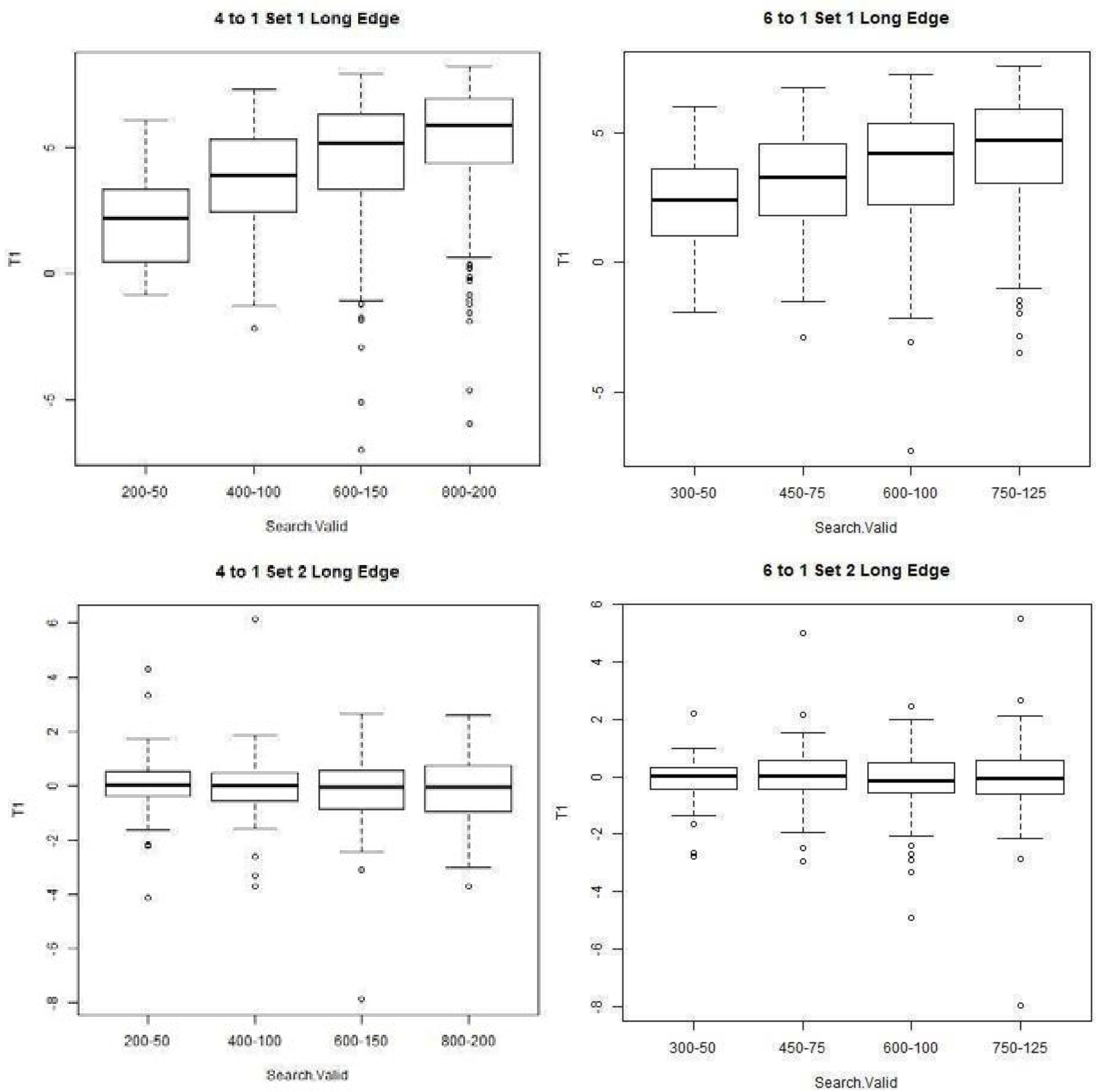
The large number of observed failures directly results from the constraints placed on the way the Search and Valid windows are chosen and compared. One of the standard conditions under which the algorithm operates is the Search and Valid windows are never allowed to overlap. In some cases, especially with the short edge comparisons, the shorter length of line from which data can be selected and compared results in far fewer data points for comparison. This problem is exacerbated as the window sizes increases. For larger sizes, there simply is not enough data available to meet these conditions in all instances. Thus, this stipulation can cause the algorithm to return no T value.

Table II summarizes the instances in which the algorithm failed to return values. It can be clearly seen that the return rate decreases with the shorter line profiles as the window size increases. As a reference, set 1 has a total of 200 comparisons, set 2 has 150 comparisons and set 3 has 144 comparisons.

Table II: Cases in which the algorithm returned no T values for each window size

Long edge comparisons				
Set	100-50	200-100	500-250	1000-500
1	0	1	1	1
2	0	1	3	3
3	0	2	3	5
Short edge comparisons				
Set	100-50	200-100	500-250	1000-500
1	0	0	1	9
2	1	0	3	19
3	1	0	3	24

As a first attempt at a solution, two additional window ratios were examined: 4 to 1 and 6 to 1. It was hoped that by limiting the size of the Valid windows less spread in the data would be seen. For each new ratio, four different window sizes were chosen and the algorithm was run again following sets 1, 2 and 3 at both the long and short edge locations on the mark. For these exploratory tests the data were limited to pliers 1-25, the assumption being the abbreviated data set would be representative of the full 1-50 pliers data. Results of this examination can be found in Figures 7 and 8. This set of parameters does indeed appear to have a significant effect in reducing the number of outliers and spread of the known matches (i.e. Set 1) as compared to the 2:1 ratio data.   A slight degradation in the maximum values obtained was seen for the known matches.   Less change is seen in the results for the known non-matches (Sets 2, 3). Average values still were centered around zero and spread seemed to increase somewhat in some cases for the known non-matches.



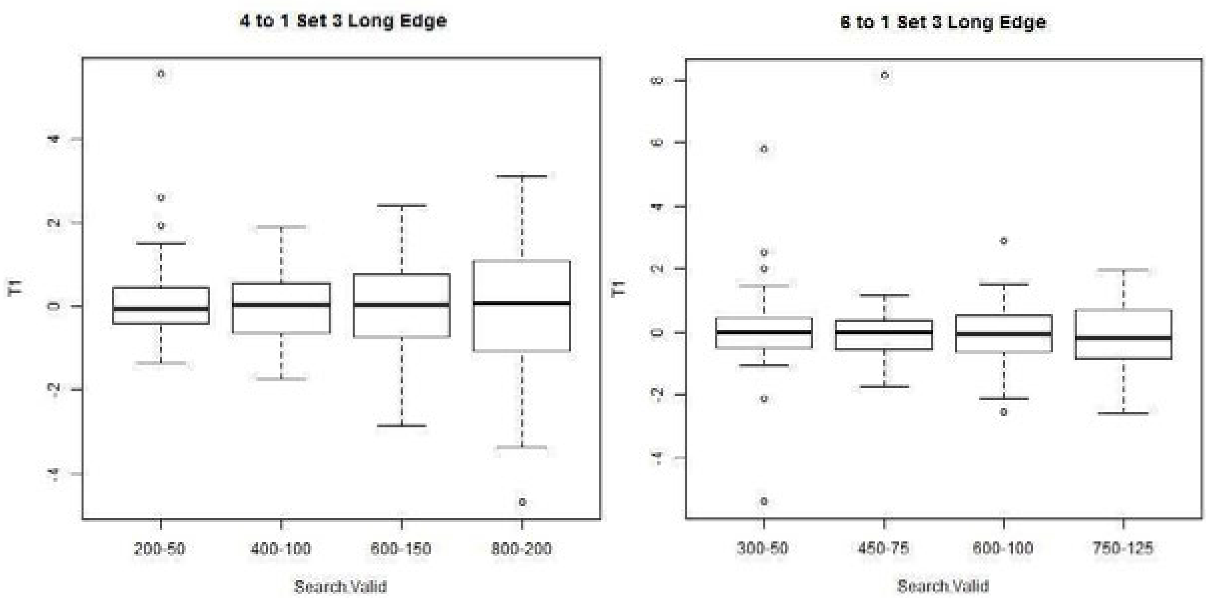
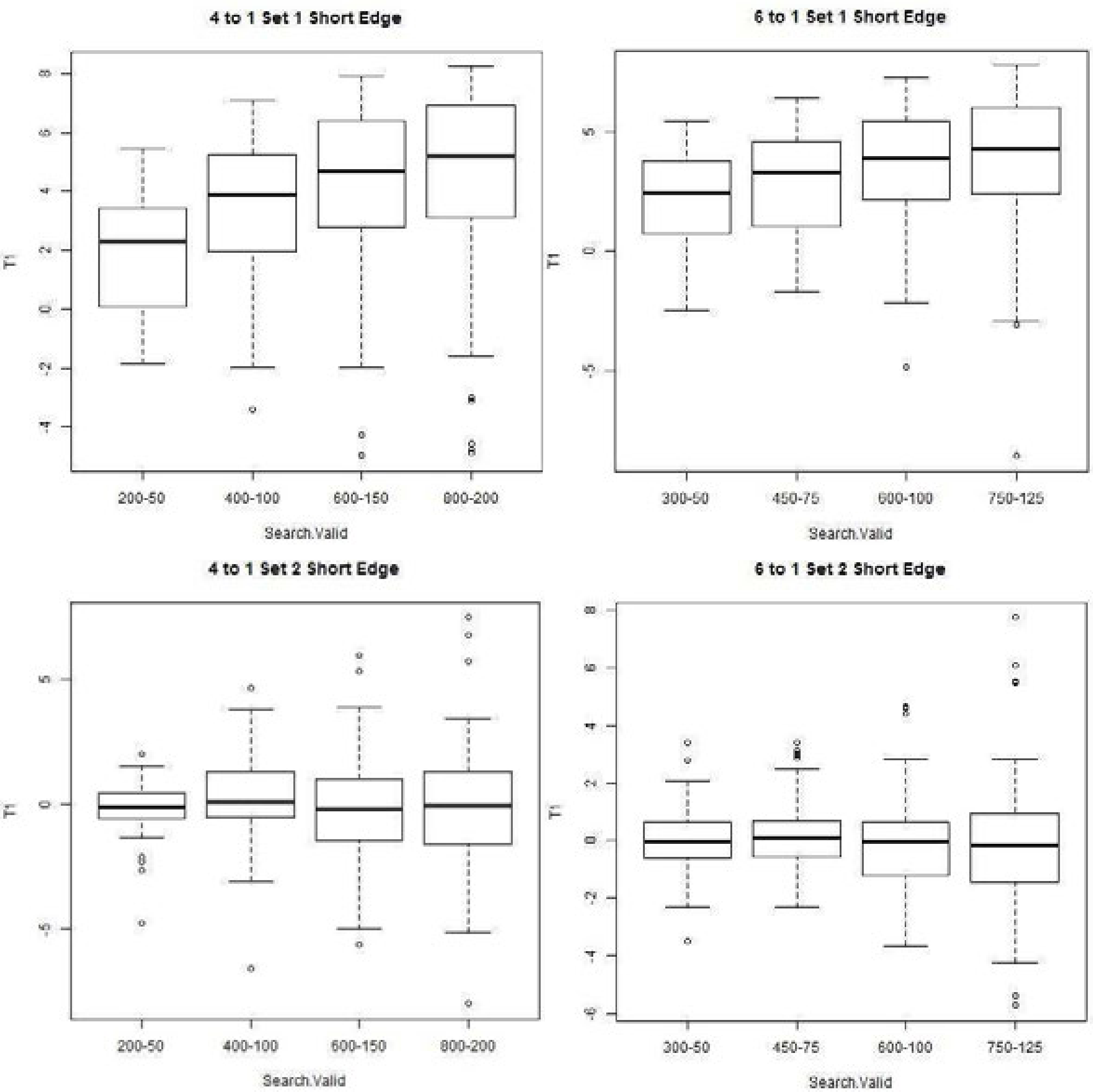


Figure 7: Results of varied ratio long edge comparisons.


4 to 1 Set 1 Short Edge
6 to 1 Set 1 Short Edge
4 to 1 Set 2 Short Edge
6 to 1 Set 2 Short Edge
T1
Search.Valid
200-50
400-100
600-150
800-200
300-50
450-75
600-100
750-125

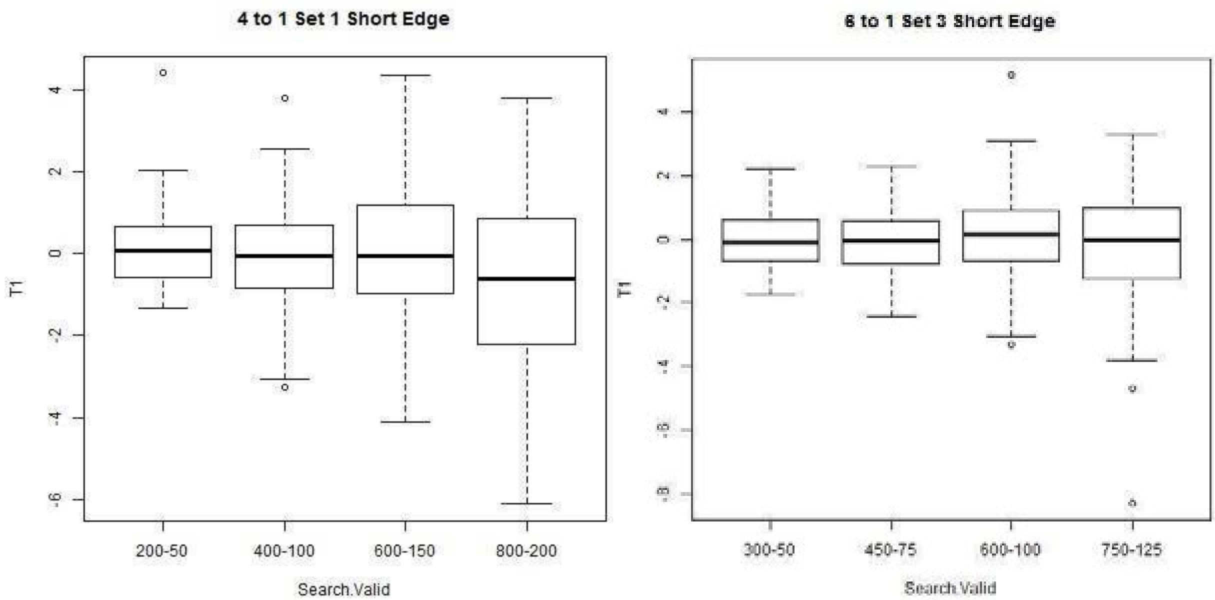


Figure 8: Results of varied ratio short edge comparisons.

Discussion

When using the developed algorithm, ideally the data should show a clear separation between T1 values for known matches as opposed to known non-matches, with no overlap occurring, even when considering outliers. While elimination of overlap in the outliers has not been achieved it is clear that a high degree of separation is seen in the majority of cases when the search parameters are adjusted from the defaults used for the striated screwdriver marks. This suggests that the current algorithm is more robust than it initially appeared, and could be suitable for discrimination if performance can be enhanced and the spread in the data can be decreased to produce complete separation between known matches and non-matches. These tests also indicate the size of the Search and Validation windows can have a critical role in determining when a match can be discriminated from a non-match. Since the size and number of Valid windows is user defined, future work must involve a series of experiments to determine what operation parameters are best suited for each individual class of marks. For example, the relatively small Search and Valid window sizes that worked well for screwdriver marks were inadequate for the plier marks. However, increasing the Search and Valid window size proved effective in producing a clear separation between known matches and non-matches for slip joint pliers and changing the size ratio has an effect on the spread of the data.

Outliers are seen in all the data sets, both known match and known non-match. Examination of these data files points to a consistent problem with the current state of the algorithm, which the authors refer to as the "opposite end" match problem. This seems to be an area where further improvements can be made. In earlier work involving screwdriver comparisons [2], it was noted the algorithm often returned false match values, incorrectly identifying the match areas on opposite ends of the mark's cross-sectional profile. "Opposite end" matches appear to occur most often in known non-matches, however non-match values have been returned for known matches as well with similar opposite end match problems. In detrending the data, many of these problems have been eliminated; however a few opposite end match problems still exist. One such example can be seen in Figure 9 for a plier comparison datafile, which consists of detrended data. One data set is shown at the top while the second is shown at the bottom. Simple chance where the opposite ends of the mark have a very similar profile over the small area of the search window, as denoted by the box, has resulted in the computer declaring an excellent match. Obviously, such a match is physically impossible, no matter how good the numbers.

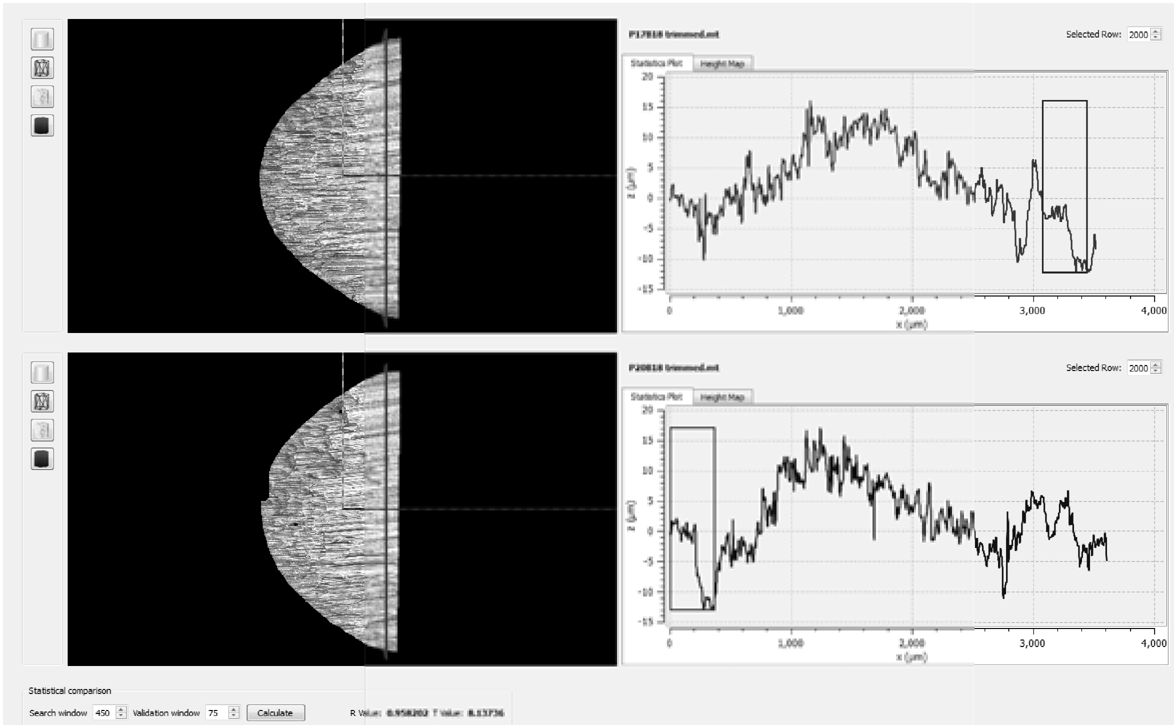
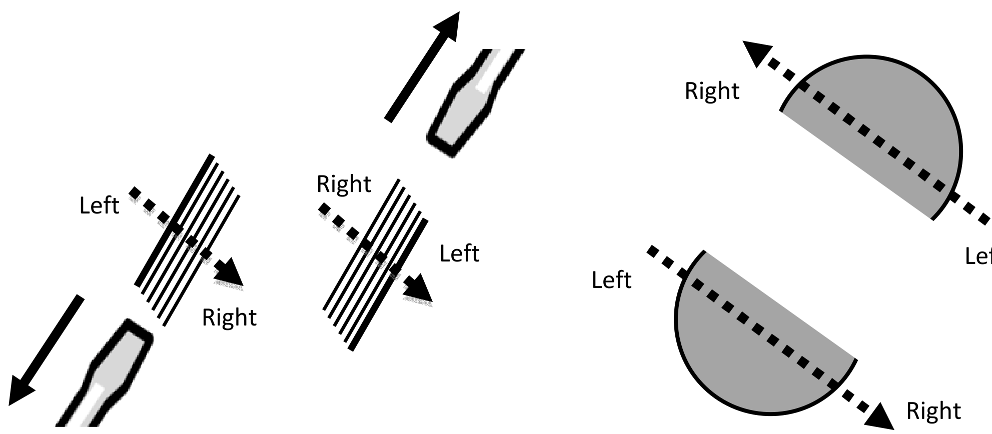


Figure 9: Incorrect opposite ends match for long edge comparison of known non-matches from different pairs of pliers. The search and valid windows were 450 and 75. T1 value is 8.137.

In its current form, the algorithm has maximum flexibility, allowing marks to be compared along a linear direction both forwards and backwards. Such a methodology requires no contextual information to be known about the mark. A fully striated mark may leave few clues as to what is the “left” side of the mark vs. the “right” side, as determined by how one holds the screwdriver, Figure 10. As shown by the bold arrows, pulling the screwdriver across the surface in opposite directions leaves the same mark, but it is rotated 180 degrees. While this situation is usually easily recognized by a trained examiner making a test mark, it is more of a problem for an automated system. To the machine, both situations result in a series of parallel lines. If the scan is constrained to run comparisons in only 1 direction (dotted line), this match may be missed since “left” could be viewed as “right” and vice versa. For this reason currently the algorithm is written to be as flexible as possible with comparisons run in both directions so it is not necessary to know which side of the mark was on the left and which was on the right as it was being made.

Determining the correct scanning direction is less of a problem for a cut wire, where contextual information such as “left” and “right” can be easily assigned due to the macroscopic shape of the object itself, Figure 10b. In this instance the situation is somewhat similar to distinguishing between class characteristics in a firearm examination.



a. b.

Figure 10: a) Fully striated marks hold few clues to “left” vs. “right for the automated scan as denoted by the dashed line. b) Cut wire sample scan directions are easily distinguishable by the macroscopic shape.

Currently each data file needs to be examined separately in order to determine whether an “opposite end” match has occurred. A screening option is being considered that will automatically determine whether an “opposite end” match has occurred and alert the user to this possibility. The user can then examine only those files so flagged and decide whether an incorrect match has occurred. Clearly, in this instance the examiner will have to use their contextual knowledge of the marks being compared to make this determination.

Summary and Conclusions

An objective analysis of 1000 cut copper wire samples produced using 50 sequentially manufactured pliers was carried out using a previous algorithm to successfully compare striated marks produced by screwdrivers. Early efforts using the algorithm produced inconclusive results when using the same parameters used successfully for the screwdriver marks. Further experiments showed changing the comparison parameters, specifically the sizes of the search and validation windows, could produce successful identification of known match/non-match comparisons. Future improvements to the algorithm are planned to screen the identified matched search windows to eliminate the possibility of clearly incorrect "opposite end" matches.

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CHAPTER 3. CLARITY OF MICROSTAMPED IDENTIFIERS AS A FUNCTION OF PRIMER HARDNESS AND TYPE OF FIREARM ACTION

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Introduction

In recent years the area of comparative forensic examinations have come under increasing attack, with various charges being made in popular literature that they are unscientific and highly subjective in nature [1, 2]. These allegations have arisen due to a combination of controversial court cases [3], mistakes in fingerprint identification [4], selective use of remarks made in a National Research Council (NRC) study on the subject of ballistic imaging [5], and a later highly critical NRC study on forensic science in general [6]. While the completeness of the latter study especially has been called into question [7] the fact remains that forensic examiners often find themselves on the defense when it comes to presenting their expert opinions.

The success of DNA evidence in providing numerical assessment of duplication made possible by known population statistics has created a call for comparative examinations to reach a similar level of confidence. Such a mandate is somewhat unreasonable given the nature of the evidence and the factors associated with the various types of analyses involved. However, there is no question that some degree of objectivity can be (and in some instances has been) introduced into comparative examinations [8]. However, a problem lies in determining by which method to apply comparative standards. This is a difficult proposition given the wide range of examinations possible, e.g. questioned documents, fingerprints, tool marks, tire impressions, shoeprints, etc. and of course, firearms. For the purposes of this paper, past efforts and current suggested solutions aimed at introducing additional objective analysis into the area of firearm and tool mark examinations will be the only area discussed.

Forensic identification of firearms and tool marks make use of the fine series of markings that are impressed or scratched on bullets, cartridges, and surfaces when they come in contact with the tool under consideration, be it a common hand tool or components of a firearm. The markings often exist in the form of a fine series of parallel scratches and one of the earliest efforts to introduce statistical analysis was suggested in 1959 by Biasotti [9]. This approach is based on observation and tabulation of groups of “consecutive matching striae” in firearm and tool mark examinations [10] and is known as the CMS method. Considerable work has been done investigating this possible technique. More recently, quantitative measurements of tool marked surfaces using surface and optical profilometers have been evaluated using a statistical algorithm to identify possible match pairs in a completely objective manner [8]. However, this study showed that trained examiners making subjective judgments are still able to distinguish between true matches and nonmatches at a higher level of success than these objective methods [8].

It is well known that using the fine markings present as a means of identification has certain problems and limitations, especially in the case of firearms, and these have been documented quite extensively [11, 12]. In recent years a method has been developed that seeks to augment traditional firearms identification by purposefully placing unique identifiers on certain critical pieces of a firearm, such as the firing pin, breech face, etc. that are stamped into a cartridge when fired [13]. Termed Microstamping, this technique has received a large amount of political and media attention.

In some cases local and state officials have introduced bills aimed at implementing microstamping of either firearms or ammunition, perhaps without a proper understanding of the process or a consideration of best practices concerning the use of this technique [14].

Certainly, one of the difficulties in any shooting investigation is to locate possible “suspect” firearms that can be test fired to generate marks that can be compared to recovered items of evidence. In theory, recovered items of evidence with microstamping could yield information that could assist investigators in locating the responsible firearm much more quickly. However, while microstamping does have the potential to greatly aid in firearm identification it clearly is not a panacea for the difficulties associated with traditional examinations. For example, the criminal can always remove firing pins, alter scratch patters by the use of abrasive polishing media, etc. Steps can be taken to minimize the effect of such alterations by use of microstamping in several places but such possibilities cannot be prevented entirely and will always exist. These considerations are not the topic of this discussion.

What is of importance and should be understood by those who suggest or are contemplating implementing laws utilizing microstamping is the effort that must be undertaken in order to optimize the microstamped mark and ensure maximum transfer of the pattern. In other words, microstamping involves more than just “blasting a number onto a firing pin using a laser”, which to the layman may seem how the technique works. For each model of firearm an optimization process must be run. The optimization process considers many physical characteristics of the area of the firing pin that strikes the primer and how the laser used for engraving interacts with this area. These characteristics would include material hardness, as well as shape, size and curvature of the firing pin. The optimum number of characters and their arrangement for maximum clarity must also be considered, along with laser parameters such as power input necessary to achieve this clarity. Thus, optimization is a complex process involving a series of experimental determinations that must be conducted for each model firearm of each manufacturer. [13]. Once completed the determined set of parameters can be applied to other firearms of the same type and material specifications in a production process. The cost of optimization becomes small once an appreciable number of parts have been produced. However, when one considers the large number of different firearm brands and models produced by any one manufacturer, the effort to optimize all possible firearms becomes a significant research project of considerable cost that must initially be undertaken. Such a project is separate and apart from the economic costs that might be incurred by a company required to adopt microstamping. The latter includes industry fears related to the purchase and maintenance of equipment, training of operators, the speed of the process and its effect on production, etc. For example, if laws requiring that unique identifiers be placed on numerous separate parts are passed, industry will have to ensure that guns are assembled as a unique set of parts, rather than in a batch process of interchangeable parts, as is currently typical.

Another consideration is the nature of the unique identifier selected for placement on each firearm. Possibly the most common perception is that microstamping would involve placing the serial number of the firearm on the firing pin. While large numbers of characters can be placed on a firing pin [15] the most viable suggestion involves placing a more limited number of identifiers on the pin, analogous to present license plates. This would provide for larger characters that are more easily produced on a firing pin, transferred during the firing process, and recognized by an examiner. By using a combination of alphanumeric characters, a six-digit code would provide a database of 36×10^6 unique designations (i.e. almost 2.2 billion possibilities), ten times the approximate number of firearms in the U.S. today. A rapid field identification then becomes a simple matter of tracing the number, in the same manner that license plates are traced today. In cases where the characters are not readily readable a subsequent examination by a trained examiner would be necessary.

However, the question then arises as to who would oversee the assignment of identifiers and maintain database integrity. Ideally, an oversight board could perform this function in much the same way as the American Society for Testing of Materials (ASTM) oversees material specifications or the

Accreditation Board for Engineering and Technology (ABET) accredits the quality of university engineering programs in this country. These organizations are voluntary societies whose stated goals are to preserve the quality of the members, industries, and institutions that they represent. A similar arrangement, possibly consisting of sportsman associations, industry representatives, and advocacy groups, might be formed to maintain a database and assign codes to participating companies that choose to implement microstamping. The goal of the group would be to ensure that database integrity is safeguarded while at the same time offering material assistance to law enforcement agencies.

Given the above considerations it is apparent that legitimate questions exist related to both the technical aspects, production costs, and database management associated with microstamping that should be addressed before wide scale implementation is legislatively mandated. However, it should be noted that none of the above objections are inherently insurmountable. While it is likely that microstamping will never approach the discriminating power associated with DNA evidence, it is a viable method for providing rapid identification of a firearm in many cases, possibly decreasing the current high workload of forensic examiners.

The purpose of this exploratory study is to examine one aspect of microstamping, namely, the performance of a microstamped identifier on a small test set as a function of ammunition brand, hardness, and firearm action type. Three different firearms representing the two most common operating principles for semiautomatic pistols were chosen as well as 10 different brands of ammunition. The results of the study and discussions concerning the various effects of primer hardness and firearm brand are presented below. It is hoped that studies of this type can guide future decisions as to the nature of the microstamped identifier that should be used, the probability of unambiguous transfer, and the parameters that most affect clear transfer of the identifier.

Experimental

The test set for this study involves use of three different 9mm semiautomatic handguns, namely, a Sig Sauer model P226 semiautomatic pistol (short recoil action), a Taurus model PT609 semiautomatic pistol (short recoil action) and a Hi-Point model C9 semiautomatic pistol (simple blowback action) where the firing pin also acts as an ejector. These guns were selected to represent a range of performance and ejection properties and the actions are typical of the types of that leave fired cartridges at crime scenes. Additionally, the firearms represent three different market price points, the Sig Sauer being a higher priced firearm, the Taurus a medium priced item, and the Hi-Point being a lower priced firearm.

Microstamping of the firing pins was optimized for a 6 character alphanumeric code and a circumferential gear code for each firearm, which is intended to confirm the alphanumeric code. The gear code is deciphered by dividing the circular code into eight equal sectors, excluding the wedge at the top of the gear code in Figure 1. Beginning at the wedge, the code is read clockwise. Within each sector, the notches are read as a six-bit binary code. For example, the first sector is read as 011001, which corresponds to the letter “S” and the first identifier in the alphanumeric code. Subsequent sectors correspond to the alphanumeric identifiers being read left to right. Further details concerning use and interpretation of the gear code are available in the literature [13].

The optimization process involved a cycle of fire analysis to ensure optimal mark transfer by identifying the surfaces, locations and vectors that provide the highest capability of transfer and repeatability [13]. Both codes are designed to act in different ways to the multivariate kinetic motion and the various instability vectors acting upon the cartridge during the cycle of fire. Both codes are designed to be spatially out of phase with each other, ensuring that degradations (such as pin drag and smear) which might wipe out certain characters in one code provide a high probability of survivability for that character on the other code surface. Reading both codes provides a means of extracting the final code. One example of a stamped impression is shown in Figure 1, imaged using a scanning electron microscope (SEM).

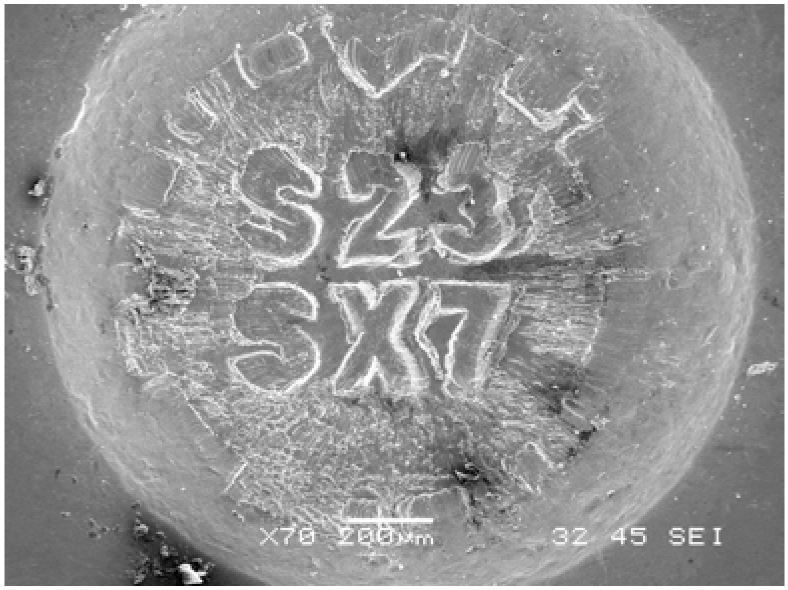

Figure 1: SEM image of a microstamped mark on a cartridge fired by the Sig-Sauer. Note the gear code surrounding the alpha-numeric identifier.

The ammunition chosen for the study represents a considerable range of possibilities. Ammunition brands were selected with a consideration of primer hardness [15] and a desire to include sealant coated and manufacturer imprinted primers. Ten different brands were selected and are listed in Table I in the order in which they were fired from the handguns. Before firing all of the cartridges were marked using an electric scribe with a letter to denote the firearm used and then sequentially marked from 1 to 1000 to make the firing sequence identifiable, Figure 2a. Thus, the T 306 cartridge was the 306th cartridge fired by the Taurus pistol. The order of ammunition used was randomly selected by drawing names out of a hat.

The cartridges were loaded ten at a time into a magazine and fired. The highest shot order number being loaded first and the lowest shot order number loaded last. The lowest number would then be fired before the higher numbers. In the event a cartridge did not fire on the first try, the cartridge was not removed from the chamber and a second pull of the trigger was tried (in the Sig-

Sauer and Taurus pistols that were both single action and double action). If the cartridge failed to fire on the second try, no further attempts to fire it were made and the misfired cartridge was placed in order with the fired cartridge cases. A second attempt at firing was not carried out using the Hi-Point pistol, which is only single-action. The spent rounds were collected during firing using a lightweight cage / net that could be affixed to the gun hand of the person conducting the firings, Figure 2b.

Table I: Ammunition brands studied.

Firing Order	Ammunition Brand	Primer Type	Cartridge Material	Description
1	Brown Bear	Berdan	Lacquered Steel	115 gr., full metal jacket, brass primer
2	DAG	Boxer	Brass	124 gr., full metal jacket, brass primer
3	Federal - American Eagle	Boxer	Brass	115 gr., full metal jacket, nickel primer
4	Remington - UMC	Boxer	Brass	115 gr., Flat Nose Enclosed Base, nickel primer, letters “H F” stamped into the primer
5	PMC	Boxer	Brass	115 gr., full metal jacket, brass primer
6	Silver Bear	Berdan	Zinc-plated steel	115 gr., full metal jacket, brass primer
7	CCI Blazer	Boxer	Aluminum	115 gr., full metal jacket, nickel primer
8	Cor-Bon	Boxer	Brass	147 gr., full metal jacket, nickel primer
9	Independence	Boxer	Brass	115 gr., full metal jacket, nickel primer
10	Sellier & Bellot	Boxer	Brass	115 gr., full metal jacket, brass primer, covered with red lacquer sealant

The pistols were cleaned after each 100 rounds. Cleaning consisted of brushing out the bore with a nylon brush soaked in “PRO-SHOT 1 Step Gun Cleaner & Lubricant”. The bore was then wiped out with a clean cotton flannel cleaning patch. The breech was thoroughly brushed using a tooth-brush like commercial nylon brush. The top of the magazine and magazine follower were wiped with an oily cleaning patch.

The fired cartridge cases were placed back into the original box/tray from which they came and the box was labeled with the pistol letter designation and the corresponding shot order numbers. Thus a box labeled S601—S650 would contain shots 601 through and including shot 650 fired by the Sig Sauer pistol. Cartridges missing from a tray would reflect casings that could not be found at the firing range.

Figure 2: a) Unfired cartridge with inscribed identifier. b) Firing in progress with catch-basket.

After firing the primers of the cartridges were examined and graded as to the quality of the microstamped impression. In conducting an assessment of this nature it becomes a matter of concern whether a character is truly visible or whether the examiner, knowing what the character is supposed to be, unconsciously ascribes greater clarity than actually exists. For example, after seeing 95 clear impressions of a code it would be difficult to not immediately interpret the 96th cartridge as being clear, even though some smearing may be present. Ideally one would want a different person to view each separate cartridge without knowing what the identifier was supposed to be. This was obviously not possible in this study. In order to somewhat account for this possibility two examinations were undertaken. Firstly, Mr. Kreiser examined the cartridges and was instructed to be conscientiously conservative in assigning his assessment. The examination involved use of a stereomicroscope equipped with a polarized light for illumination and a simple rubric where the number of characters clearly visible using a stereoscopic examination was tabulated. Thus, a “C6” assessment means all six characters were clearly visible while a “C3” would mean only three characters could be read easily immediately. For this examination only the alphanumeric identifier was evaluated and observations concerning multiple stamped identifiers, misfires, etc. were also noted. Secondly, the cartridges were viewed and evaluated by T. Grieve, who has no training in forensic examinations at all. The examination again involved a stereomicroscope with a polarized light source. In addition to the alphanumeric identifier she examined whether there was any observable transfer of the gear code. This evaluation was qualitative and did not determine what percentage of the code was visible, only whether any useable portion survived. Thus, a “Y” evaluation meant that at least part of the code transferred while “N” meant none was visible.

Note that the evaluation rubric employed by Mr. Kreiser might represent a “worst case scenario” for the alphanumeric identifier while that used by Ms. Grieve is a “best case scenario” for the gear code. Neither evaluation rules out the possibility of identifying either more characters or more of the gear code using a more advanced imaging technique, nor does it necessarily preclude reconstructing the entire code [13]. As an example of what might be visible using a more advanced technique, certain cartridges having low C and gear code ratings were examined using a JEOL SEM capable of both secondary (SEI) and backscattered (BES) electron imaging. Both imaging techniques were used and the best images were chosen for presentation.

Vickers hardness measurements of the primers from the 10 selected ammunition types were made using a LECO LM 247 AT microhardness tester. Loading was set at 50g and dwell time was 13 seconds. The measurements were made on the already fired primers as far as possible from the firing pin impression in order to minimize any work hardening effects.

Results

Microstamp Evaluation:

The results of the stereo-observations are summarized below in Tables II-IV. The data is summarized both by firearm used and by brand of ammunition. The totals displayed in Table II confirm that the ratings by J. Kreiser are more conservative as anticipated and discussed above. It is also apparent from examination of Table II that the results show a strong correlation between that the transfer of the identifier and the price point of the firearm, i.e. the most advantageous transfer occurs for the Sig-Sauer, the worst by the Hi-Point.

The lacquer present on the Sellier & Bellot ammunition initially prevented clear observation of the numbers and gear codes for the Taurus and Hi-Point fires, so cartridges 901-1000 for these firearms were not graded by J. Kreiser and therefore are not shown in Table II. This results in somewhat lower totals for the Taurus and Hi-Point samples. The optical analysis carried out by T. Grieve is delineated in Table II by the use of italics. Note that the lacquer was subsequently removed from 95 of the cartridges after J. Kreiser had examined them and before T. Grieve conducted her examination. *(Note: Five cartridges with lacquer were reserved to conduct further imaging experiments on at a later time) and the totals obtained are included in the comments section. In either case, it is clear that the use of lacquer has significantly degraded the ability to achieve total identifier transfer.*

Table II: Quality of microstamp as a function of firearm. Note that the numbers are out of 1000 fires for the Sig Sauer, out of 900 for the Taurus and Hi-Point. T. Grieve numbers in italics.

Strike Grade Summary							
Sig Sauer							**Comments**
C6	**C5**	**C4**	**C3**	**C2**	**C1**	**C0**	Cartridge #808 was lost and not graded or included in the totals. There were 36 C6 double impressions. There were 3 C5 double impressions. *Cartridges S901-S1000 were graded after the lacquer was removed by T. Grieve.*
948	30	14	5	1	0	2	
968	*19*	*7*	*2*	*1*	*1*	*2*	

Table II (Continued)

Taurus							
C6	**C5**	**C4**	**C3**	**C2**	**C1**	**C0**	There were 26 C6 double impressions, 1 C5 double impression, 1 C4 double impression and 1 C1 double impression. 3 C6 misfires appeared. Cartridges 901-1000 ungraded by J. Kreiser. *Cartridges T901-T1000 graded after the lacquer was removed by T. Grieve produced C6:56, C5:26, C4:10, C3:1, C2:1, C1:0, C0:0*
848 *854*	43 *35*	3 *5*	1 *3*	3 *2*	2 *1*	0 *0*	
Hi-Point							
C6	**C5**	**C4**	**C3**	**C2**	**C1**	**C0**	There were 52 C6 double impressions, 14 C5s, one C4, one C3 and one C2. There was one C6 triple impression. Of the 12 misfires, 6 were C6, 4 were C5, 1 was C4 and 1 was C0. Cartridges H901-H1000 ungraded by J. Kreiser. *Cartridges H901-H1000 graded after the lacquer was removed by T. Grieve produced C6:49, C5:15, C4:12, C3:8, C2:4, C1:5, C0:2*
663 *684*	139 *113*	47 *65*	26 *25*	15 *7*	5 *4*	4 *1*	

It is interesting that it was often found that poorly marked cartridges would be grouped together. This tendency was seen for all firearms but clearly occurred more often for the lower cost Hi-Point. For example, for the Hi-Point 125 of the 237 non-C6 ratings found by Kreiser came in runs of two to five consecutive cartridges. The tendency for multiple groups of poorly marked cartridges seemed to be exacerbated by the presence of lacquer. For example, of the 52 non-C6 ratings found by Kreiser for the Sig Sauer firings, eight groups of two and one run of nine non-C6 ratings occurred, i.e. 25 out of 52, all in the Sellier & Bellot cartridges. For the Taurus both Kreiser and Grieve found four runs of two or more for the non-Sellier & Bellot ammunition; in the Taurus Sellier & Bellot cartridges Grieve noted an additional six runs of two or more, the largest run being six consecutive non-C6 ratings.

Table III: Quality of microstamp as a function of ammunition, J. Kreiser results.

Summary of Cartridge Types								
Brown Bear (#1-100)								**Comments**
Gun	**C6**	**C5**	**C4**	**C3**	**C2**	**C1**	**C0**	
Sig	99	1	0	0	0	0	0	
Taurus	93	7	0	0	0	0	0	2 misfires, C6
Hi-Point	92	7	1	0	0	0	0	1 triple impression

Table III (Continued)

DAG (#101-200)							
Gun	**C6**	**C5**	**C4**	**C3**	**C2**	**C1**	**C0**	
Sig	99	0	1	0	0	0	0	
Taurus	89	9	1	0	1	0	0	
Hi-Point	86	8	2	3	0	0	1	Ctg. 159 pierced
Federal American Eagle (#201-300)								
Gun	**C6**	**C5**	**C4**	**C3**	**C2**	**C1**	**C0**	
Sig	97	3	0	0	0	0	0	
Taurus	92	2	1	1	2	2	0	
Hi-Point	62	23	8	3	2	1	0	Ctg. 251 lost
Remington UMC (#301-400)								
Gun	**C6**	**C5**	**C4**	**C3**	**C2**	**C1**	**C0**	Existing letters create interference with strike pattern
Sig	99	1	0	0	0	0	0	
Taurus	91	9	0	0	0	0	0	
Hi-Point	92	6	2	0	0	0	0	
PMC Bronze (#401-500)								
Gun	**C6**	**C5**	**C4**	**C3**	**C2**	**C1**	**C0**	
Sig	100	0	0	0	0	0	0	
Taurus	99	1	0	0	0	0	0	
Hi-Point	64	25	9	1	1	0	0	
Silver Bear (#501-600)								
Gun	**C6**	**C5**	**C4**	**C3**	**C2**	**C1**	**C0**	
Sig	99	0	1	0	0	0	0	
Taurus	89	10	1	0	0	0	0	
Hi-Point	58	20	8	7	4	1	2	4 misfires, C6
CCI Blazer (#601-700)								
Gun	**C6**	**C5**	**C4**	**C3**	**C2**	**C1**	**C0**	
Sig	99	1	0	0	0	0	0	
Taurus	98	2	0	0	0	0	0	
Hi-Point	73	15	5	5	0	2	0	1 misfire, C6
Cor-Bon (#701-800)								
Gun	**C6**	**C5**	**C4**	**C3**	**C2**	**C1**	**C0**	
Sig	96	2	1	0	0	0	1	
Taurus	97	3	0	0	0	0	0	
Hi-Point	67	22	6	1	3	0	1	4 C5 misfires, 1 C4 misfire and 1 C0 misfire
Independence (#801-900)								
Gun	**C6**	**C5**	**C4**	**C3**	**C2**	**C1**	**C0**	
Sig	99	0	1	0	0	0	0	
Taurus	100	0	0	0	0	0	0	

Hi-Point	69	13	6	6	5	1	0	1misfire, C6
Sellier & Bellot (#901-1000)								
Gun	**C6**	**C5**	**C4**	**C3**	**C2**	**C1**	**C0**	
Sig	61	22	10	5	1	0	1	
Taurus	-	-	-	-	-	-	-	Lacquer prevented observation in Taurus and Hi-Point
Hi-Point	-	-	-	-	-	-	-	Lacquer prevented observation in Taurus and Hi-Point

Table IV: Quality of microstamp as a function of ammunition, T. Grieve.

Summary of Cartridge Types									
Brown Bear (#1-100)								**Comments**	
Gun	**C6**	**C5**	**C4**	**C3**	**C2**	**C1**	**C0**		
Sig	95	2	0	1	1	1	0	Y=100	N=0
Taurus	89	11	0	0	0	0	0	Y=0	N=100
Hi-Point	86	13	1	0	0	0	0	Y=95	N=5
DAG (#101-200)									
Gun	**C6**	**C5**	**C4**	**C3**	**C2**	**C1**	**C0**		
Sig	94	3	2	1	0	0	0	Y=81	N=19
Taurus	97	1	1	1	0	0	0	Y=0	N=100
Hi-Point	89	3	4	2	0	2	0	Y=95	N=5
Federal American Eagle (#201-300)									
Gun	**C6**	**C5**	**C4**	**C3**	**C2**	**C1**	**C0**		
Sig	99	1	0	0	0	0	0	Y=100	N=0
Taurus	95	1	0	1	2	1	0	Y=55	N=45
Hi-Point	64	23	8	3	1	0	0	Y=95	N=4
Remington UMC (#301-400)									
Gun	**C6**	**C5**	**C4**	**C3**	**C2**	**C1**	**C0**		
Sig	99	1	0	0	0	0	0	Y=100	N=0
Taurus	98	2	0	0	0	0	0	Y=0	N=100
Hi-Point	89	7	4	0	0	0	0	Y=98	N=2
PMC Bronze (#401-500)									
Gun	**C6**	**C5**	**C4**	**C3**	**C2**	**C1**	**C0**		
Sig	100	0	0	0	0	0	0	Y=100	N=0
Taurus	100	0	0	0	0	0	0	Y=0	N=100
Hi-Point	63	16	13	7	1	0	0	Y=98	N=2
Silver Bear (#501-600)									
Gun	**C6**	**C5**	**C4**	**C3**	**C2**	**C1**	**C0**		
Sig	99	1	0	0	0	0	0	Y=93	N=7
Taurus	82	13	4	1	0	0	0	Y=0	N=99
Hi-Point	63	14	12	5	3	2	1	Y=86	N=14
Blazer (#601-700)									
Gun	**C6**	**C5**	**C4**	**C3**	**C2**	**C1**	**C0**		
Sig	100	0	0	0	0	0	0	Y=100	N=0
Taurus	99	1	0	0	0	0	0	Y=0	N=100
Hi-Point	83	12	3	2	0	0	0	Y=94	N=6

Table IV (Continued)

Cor-Bon (#701-800)								
Gun	**C6**	**C5**	**C4**	**C3**	**C2**	**C1**	**C0**	
Sig	98	0	1	0	0	0	1	Y=97 N=3
Taurus	95	5	0	0	0	0	0	Y=0 N=100
Hi-Point	74	13	9	3	1	0	0	Y=91 N=9
Independence (#801-900)								
Gun	**C6**	**C5**	**C4**	**C3**	**C2**	**C1**	**C0**	
Sig	99	1	0	0	0	0	0	Y=100 N=0
Taurus	99	1	0	0	0	0	0	Y=0 N=100
Hi-Point	73	12	11	3	1	0	0	Y=97 N=3
Sellier & Bellot (#901-1000)								
Gun	**C6**	**C5**	**C4**	**C3**	**C2**	**C1**	**C0**	Lacquer removed from cartridges
Sig	85	10	4	0	0	0	1	Y=77 N=23
Taurus	56	26	10	1	1	0	0	Y=0 N=95
Hi-Point	49	15	12	8	4	5	2	Y=78 N=17

SEM Evaluation:

After the optical examination a few of the lower-scoring cartridges were selected for SEM examination. One example from each of the firearms used is shown below. Figure 3 shows cartridge #S198, rated as C3-Y by T. Grieve and C4 by J. Kreiser. For comparison see Figure 1, obtained from a cartridge rated as a C6-Y.

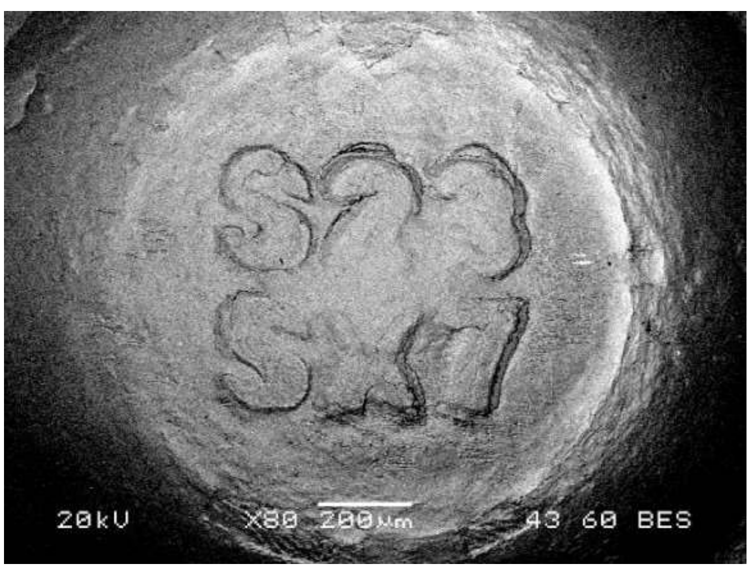

Figure 3: SEM imaging of cartridge #S198, DAG ammunition, Sig Sauer handgun

It is left to the reader as an unbiased observer to decide how many of the alphanumeric characters are visible. To the authors (who, admittedly, know the code) it appears the code is S23SX7, i.e. complete identification can be made using a higher quality image. The gear code, though visible, is difficult to discern in small regions of this particular cartridge. Figure 4 shows an example cartridge from the Taurus, #T944. Rated a C2-N optically by T. Grieve (not rated by J. Kreiser due to the lacquer), this example shows the problems involved when using a lacquered cartridge. The four alphanumerics at the corners, difficult to discern using optics, are clearly visible using SEM, being T13A5L. The gear code is totally lacking, and in general the gear code did not transfer for the Taurus handgun.

An example from the Hi-Point series is shown in Figure 5. The Hi-Point had the poorest transfer of the alphanumeric, although a high percentage of the cartridges had some gear code available, causing a much higher rating in this area than the Taurus. Figure 5 makes it clear, however, that the gear code was present over a relatively small area, in this case the upper right quadrant. Rated as a C2-Y optically by T. Grieve and C3 by J. Kreiser, SEM imaging in this case sheds little light on the identifier, possibly allowing one additional character of the identifier H60PZE to be visible.

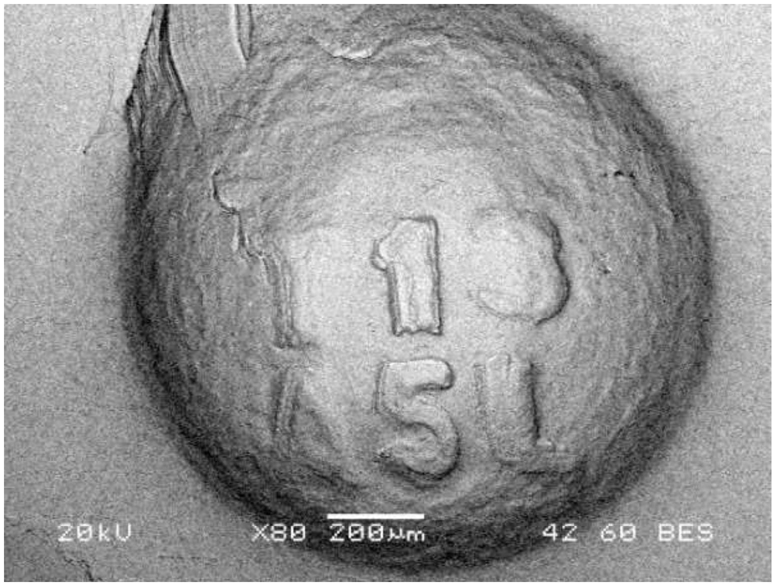

Figure 4: Cartridge #T944, Sellier & Bellot ammunition, Taurus handgun

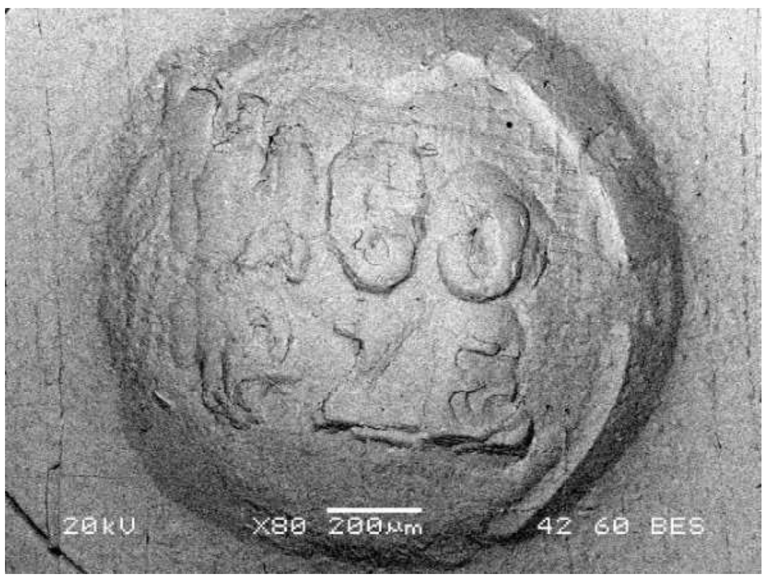

Figure 5: Cartridge #H519, PMC ammunition, Hi-Point handgun

Hardness Evaluation:

The primer hardness values obtained from the 10 types of ammunition used are shown in Table V. The presence of lacquer on the Sellier and Bellot cartridges presents a special problem when measuring hardness. Just as it is clear that the lacquer prevents an immediately recognizable mark transfer while it remains on the cartridge, evaluating the hardness with the lacquer present is meaningless since the soft nature of the lacquer disrupts the method used to measure hardness, producing meaningless results. Thus, the lacquer was removed and the values reported in Table V reflect the actual hardness of the uncoated primer.

Table V: Vicker's Hardness of the ammunition studied.

Ammunition Type	Average Hardness (HV)	Primer type	Comments
Brown Bear	157.88	Brass	284 total C6
DAG	177.71	Brass	274 total C6
Federal American Eagle	165.30	Nickel	251 total C6
Remington UMC	236.31	Nickel	282 total C6; Primer contained manufacturer-stamped letters
PMC Bronze	150.29	Brass	263 total C6
Silver Bear	162.80	Brass	246 total C6
CCI Blazer	176.62	Nickel	270 total C6
CorBon	164.38	Nickel	260 total C6
Independence	167.17	Nickel	267 total C6
Sellier &Bellot	160.68	Brass	Lacquer coated Primer, removed for hardness tests.

Discussion

It seems clear from the above results that both brand of ammunition and type of firearm play a role in identifier transfer. When considering ammunition no primary parameter could be identified as ensuring complete identifier transfer, i.e., no consistent trends were observed as a function of either primer material, type or hardness, and/or cartridge case material. For example, if one simply uses the total number of C6 ratings per ammunition type as a rough comparison system, the three highest rated ammunitions are the Brown Bear (115 gr., brass primer, 157.88 Hv), the UMC (115 gr., nickel primer, 236.31 Hv), and the DAG (224 gr., brass primer, 177.71 Hv). Given that the transfer quality does vary substantially, further study is necessary before any definitive statements can be made concerning the effect of ammunition type. However, it is clear that the presence of lacquer is of paramount importance in identifier transfer. For example, for the Sig Sauer results examiner J.

Kreiser scored 52 non-C6 marks, 39 of which were seen in the Sellier & Bellot before the lacquer was removed, i.e. 75% of the poor markings came in the lacquered ammunition. The effect of the lacquer was so great on the Taurus and Hi-Point marks that Mr. Kreiser did not even attempt to rate these cartridges. Even after removal of the lacquer the effect was still apparent; Ms. Grieve found that 15 of the 32 non-C6 marks she recorded for the Sig Sauer (47%) came from the Sellier & Bellot cartridges and 38 of 90 for the Taurus (42%). For the Hi-Point 46 of the 95 Sellier & Bellot cartridges examined (48%) were non-C6.; this compares to an average of 24% non-C6 ratings for the rest of the ammunition types examined.

The type of firearm seems to play the largest role in the overall quality of identifier transfer. Depending on whose evaluation you chose to use, success rate for a C6 transfer for the Sig-Sauer was in the range 95-97%, for the Taurus 91-94%, and for the Hi-Point 68-74%. The firearms used were specifically selected to cover a range of pistol operating systems and prices and it is clear that the higher priced firearms, possessing a short recoil action, result in the transfer of a more easily distinguishable identifier than the Hi-Point which has a simple blowback mechanism with a firing pin ejector.

It should be noted that the firing pin is involved in the ejection of spent cartridges from the Hi-Point, and is necessarily in contact with the primer during this time. This makes it difficult to say whether the multiple strike marks seen on spent cartridge primers from the Hi-Point came solely from a multiple strike scenario (as would be the case for the Sig Sauer and Taurus firearms) or whether the ejection mechanism also contributed to the multiple markings. It is certainly true that the Hi-Point suffered a much higher rate of multiple markings than did either the Sig Sauer or the Taurus.

The poor transfer of the gear code in the case of the Taurus was investigated by examining additional firing pins that had also been microstamped using the same identifier for the purposes of this study. SEM images of the pins, shown in Figure 6, reveal that while the alpha-numeric number is clear the gear-code is somewhat sparse in detail compared to the Sig Sauer cartridge of Figure 1, and is not as clearly defined in some areas, particularly in the arc quadrant encompassing the “A” of the identifier.

Figure 6: SEM backscattered images of three pins microstamped for the Taurus firearm.

Measurement of the radii of curvature of the firing pins for the three handguns examined revealed that the curvature of the Taurus pins is much greater than either the Sig Sauer or Hi-Point, the radii being 664 microns, 883 microns, and 1180 microns, respectively. Presumably this makes it harder for the gear code on the Taurus to effectively mark a primer.

Although the complete identifier did not mark in every case, this is not to say that it could not have been reconstructed using more advanced imaging techniques. SEM imaging in many cases could reveal more of the identifier and gear code than was visible using simple optics. Previous studies [13] have shown that a combination of better imaging, examination of multiple cartridges from the same weapon and a careful analysis of the gear code can bring out additional information that is not immediately obvious by a simple examination. Such detailed studies again would have to be conducted by a forensic examiner trained in the use of both the necessary equipment and the methodologies used. Whether a simple optical examination using a low-powered magnifying glass by an untrained examiner is possible is a matter that needs to be investigated, and efforts are underway to secure funding to conduct a blind study of this type.

Summary and Conclusions

In this study 10 different ammunition brands were fired from three different brands of firearms that were equipped with firing pins containing a unique microscopic identifier. Differences in the clarity of the microstamped identifier were evaluated using simple observation employing a stereomicroscope. While some differences in clarity were seen as regards brand of ammunition, the observed results could not be related to most of the ammunition variables examined, which included primer material (brass vs. nickel), hardness, type (Boxer vs. Berdan), or cartridge material (brass, aluminum, or steel). The only obvious difference in quality occurring when using lacquered ammunition, which degraded identifier transfer. Greater differences were seen when comparing the type of firearm, where the Hi-Point transferred less well than the Sig Sauer or Taurus. However, while the Taurus alphanumeric identifier transferred extremely well the gear code transferred either very poorly or not at all.

While readable microstamping was achieved on most of the cartridge cases, it was also clear that it is not a perfect technology, even on optimized weapons, as the poorer transfer of the Taurus gear code would indicate. As discussed in previous papers the interaction of any particular brand of ammunition with any given firearm is stochastic in nature [16]. Such a variable process prevents perfect transfer in all cases and makes interpretation of the results of this study difficult as regards primer hardness effects.

Despite shortcomings, microstamping does have the potential to place valuable information into the hands of the officer or detective at the scene of a crime in a timely fashion. If coupled with an independent, voluntary oversight board, established and maintained by firearm manufacturers and sportsman associations to control issuance of the identifier and maintain privacy, microstamping could enable tracking of fired cartridges in an efficient and timely manner.

Acknowledgments

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CHAPTER 4. GEAR CODE EXTRACTION FROM MICROSTAMPED CARTRIDGES

A paper published by *The Association of Firearm and Toolmark Examiners Journal*, Volume 45, Number 1, pp. 64-74

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Introduction

Over the past few years, intentional firearm microstamping has received a large amount of attention from technical discussions [1-4], lawmakers [5], and the media [6-8]. Microstamping involves placing alpha-numeric identifiers onto the surface of various components associated with the firing of a firearm, such as the firing pin or breech face. These unique identifiers are then automatically transferred to the cartridge upon firing due to the forces involved in the action. While microstamping can be used to transfer large numbers of characters [9] more effort has been devoted toward and eight character alpha-numeric on the firing pin tip with a circular gear code around the circumference of the pin [2]. It is proposed that these microstamped identifiers can be used as a simple, objective, and rapid means of identification of a particular gun, similar to the way a license plate identifies a particular car. An example of a microstamped mark showing both alpha-numeric identifier and circular gear code is shown in Figure 1.

While simple visual observation can determine what the identifiers are if the microstamping is clear, distortion of the transfer makes their identification much more difficult. If the alpha-numeric characters are deformed, or partially removed due to the firing and cartridge ejection process, the only means of identification for the original microstamped identifier might be the gear code. Thus, the gear code could provide important information that could either fill in any gaps in a distorted alpha-numeric code, or be used to replicate the code if the alpha-numeric identifier is entirely illegible.

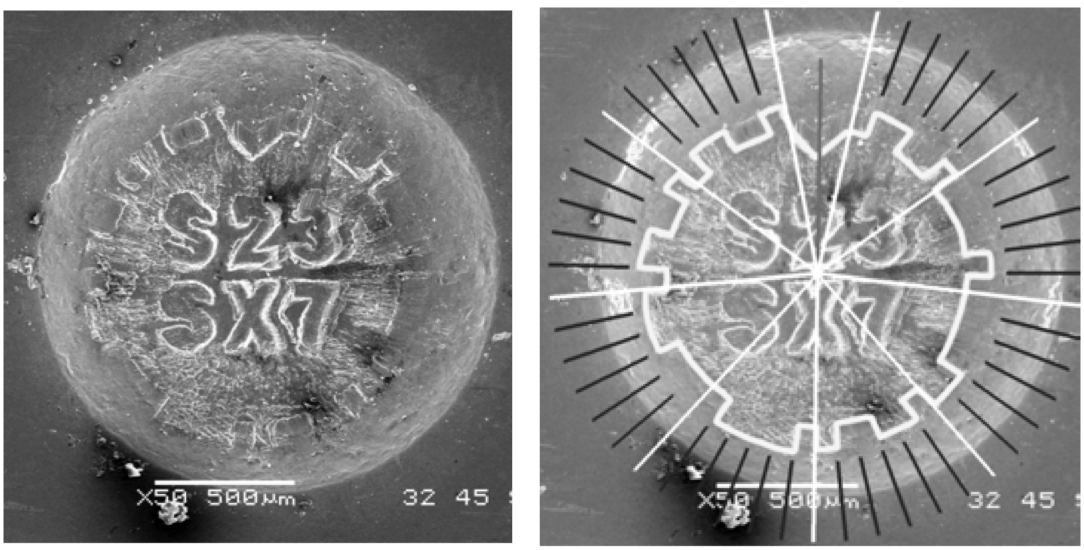

Figure 1: a) Microstamped mark from a Sig Sauer P226 semiautomatic handgun. b) Microstamped mark with gear code overlay.

The gear code is deciphered by dividing the circular code into eight equal sectors, excluding the wedge at the top of the gear code, which marks the start of the sequence (see gray line in Figure 1b). This translates to eight sectors of 42 degrees, delineated in Figure 1b by straight, white lines. The code is then read clockwise, in six bit binary, where each bit is a 7 degree increment, as shown in Figure 1b by black lines. The numbers "0" and "1" then correspond to whether the primer is left in the unstamped or stamped condition, respectively. For example, the first section of gear code in Figure 1b is then read as 011001, which corresponds to the letter "S" and is also the first character in the alpha-numeric code. The subsequent sectors correspond to the identifiers being read left to right. Thus, in Figure 1, the second sector represents the second character, 2, the third 3, etc. The gear codes contain the numbers 0-9 and all letters of the alphabet, excluding I, O and Q to eliminate any confusion in evaluation. More information regarding gear codes, microstamping, and translation of the digital code into the alpha-numerics can be found in the literature [2]. A table showing the digital code and the corresponding alpha numeric is shown in Table I.

In this study the efficiency of transfer of gear codes from micro-etched firing pins to a variety of ammunition types is reported. This paper constitutes a follow-up to an earlier study where the alpha-numeric was examined [3]. Readers are encouraged to consult this earlier study for a full understanding of the experimental design.

Table I: Variable pitch gear code table.

Value	Code	Dig1	Dig2	Dig3	Dig4	Dig5	Dig6	Concatenate
0	0	0	0	0	0	0	0	000000
1	1	0	0	0	0	0	1	000001
2	2	0	0	0	0	1	0	000010
3	3	0	0	0	0	1	1	000011
4	4	0	0	0	1	0	0	000100
5	5	0	0	0	1	0	1	000101
6	6	0	0	0	1	1	0	000110
7	7	0	0	0	1	1	1	000111
8	8	0	0	1	0	0	0	001000
9	9	0	0	1	0	0	1	001001
A	10	0	0	1	0	1	0	001010
B	11	0	0	1	0	1	1	001011
C	12	0	0	1	1	0	0	001100
D	13	0	0	1	1	0	1	001101
E	14	0	0	1	1	1	0	001110
F	15	0	0	1	1	1	1	001111
G	16	0	1	0	0	0	0	010000
H	17	0	1	0	0	0	1	010001
I		0						
J	18	0	1	0	0	1	0	010010
K	19	0	1	0	0	1	1	010011
L	20	0	1	0	1	0	0	010100
M	21	0	1	0	1	0	1	010101
N	22	0	1	0	1	1	0	010110

Table I (Continued)

O								
P	23	0	1	0	1	1	1	010111
Q								
R	24	0	1	1	0	0	0	011000
S	25	0	1	1	0	0	1	011001
T	26	0	1	1	0	1	0	011010
U	27	0	1	1	0	1	1	011011
V	28	0	1	1	1	0	0	011100
W	29	0	1	1	1	0	1	011101
X	30	0	1	1	1	1	0	011110
Y	31	0	1	1	1	1	1	011111
Z	32	1	0	0	0	0	0	100000

Experimental

Samples examined in this paper were described in a previous study [3]. Briefly, cartridges were fired and examined using three different semiautomatic handguns: a Sig Sauer model P226 pistol, a Taurus model PT609 and a Hi-Point model C9. Six character microstamped firing pins were optimized for these guns and ten different brands of ammunition representing a range of primer hardness and types were selected. Each gun was used to fire 100 rounds of each brand of ammunition, 10 rounds per magazine, for a total of 1000 rounds per firearm. The brands of ammunition used can be found in Table II.

Table II: Ammunition brands used in the study.

Firing Order	Ammunition Brand	Primer Type	Primer Material	Description
1	Brown Bear	Berdan	Brass	115 gr., full metal jacket
2	DAG	Boxer	Brass	124 gr., full metal jacket
3	Federal - American Eagle	Boxer	Nickel	115 gr., full metal jacket
4	Remington - UMC	Boxer	Nickel	115 gr., Flat Nose Enclosed Base, letters “H F” stamped into the primer
5	PMC	Boxer	Brass	115 gr., full metal jacket
6	Silver Bear	Berdan	Brass	115 gr., full metal jacket
7	CCI Blazer	Boxer	Nickel	115 gr., full metal jacket

Table II (Continued)

8	Cor-Bon	Boxer	Nickel	147 gr., full metal jacket
9	Independence	Boxer	Nickel	115 gr., full metal jacket
10	Sellier & Bellot	Boxer	Brass	115 gr., full metal jacket, primer covered with red lacquer sealant

Evaluation of the microstamped alpha-numeric identifiers has already been published [3]. Optical grades were given based upon the number of clearly legible alpha-numeric characters visible using a stereomicroscope. If all six identifiers were clearly read, the cartridge received a grade of C6, if only five identifiers were clear, the cartridge was graded C5, etc. For the current study, only fired cartridges that received an optical grade of C2 or below were chosen for evaluation for the Hi-Point. Since the Taurus and Sig Sauer generally received better optical grades, cartridges of less than C6 were evaluated. A total of 26 cartridges of poor grades were evaluated, seven from the Sig Sauer gun, seven from the Taurus, and 12 from the Hi-Point.

The selected cartridges were cleaned and examined using a JEOL 6060LV scanning electron microscope (SEM). Pictures were taken using either secondary electron imaging or backscattered electron imaging, depending on which imaging technique made the gear code more legible. The SEM images obtained were then examined using a free photo editing software (GIMP), the outline of clear gear code was traced, and an overlay of the correct angles was placed upon the image to evaluate the gear code.

Results

As with the previous microstamp study [3], the Sig Sauer had the best transfer of gear code and legible identifiers, while the Hi-Point and the Taurus did not transfer identifiers and gear codes quite as well. In this section examples of analyses from several selected cartridges will be presented, followed by a summary of results for all of the cartridges examined.

Sig Sauer

In Figure 2, Sig Sauer cartridge number 24 (Brown Bear) graded C2 optically is shown. More detail is visible in the SEM image than when using a stereomicroscope and the identifier appears to be S23-SX7 by simple SEM examination without resorting to the gear code. In this instance the gear code is complete and can be clearly deciphered. All eight characters are visible and decode as S23-SX7-SS, which confirms the assessment of the alpha-numeric based solely on SEM imaging.

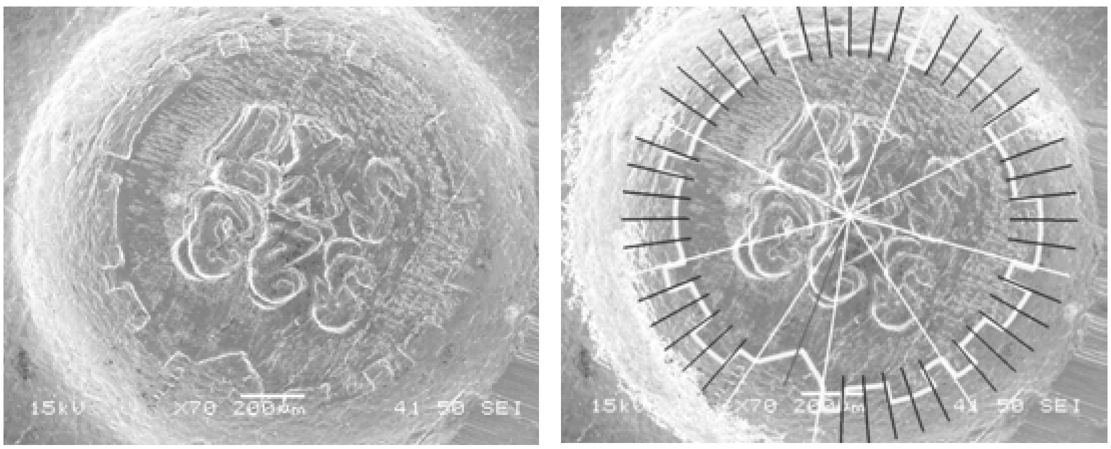

Figure 2: SEM image of a) Sig cartridge #24, Brown Bear. b) Outlined gear code and overlay.

While generally the Sig Sauer had the best and most consistent transfer [3], this was not true in all cases. Figure 3, shows an example of a poorly marked cartridge (Cor-Bon) that was graded C0 optically. The SEM image reveals more identifiers in addition to a partial gear code.

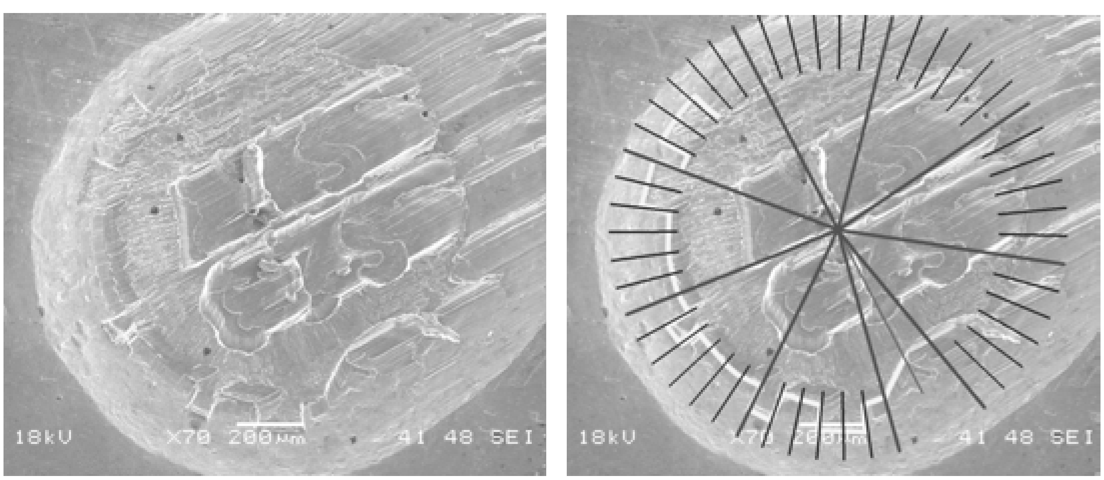

Figure 3: a) SEM image of Sig cartridge #707, Cor-Bon. b) Outlined gear code and overlay.

Estimating exactly how many of the alpha-numerics can be deciphered using SEM is somewhat artificial since the identifier is already known. While it is difficult to be totally objective, it would appear that an unbiased observer might make a reasonable guess at 2-3 of the alpha-numerics, possibly S*3 – S*7 at best, based solely on SEM imaging. While only part of the gear code can be deciphered, it still yields enough information to confirm the first three identifiers and part of the fourth. The first sector can be read as “S”, the second as “2”, the third as “3”. Complete transfer fails at the fourth identifier.

Taurus

The Taurus firing pin did not mark gear codes nearly as well as that of the Sig. This was partly due to the sharper radius of the pin [3] and partly due to the sparse gear code on the pin [3], i.e. the code consisted of large continuous areas of stamped “1” or unstamped “0”. This absence of surface relief was found to make it difficult to determine whether the cartridge was left unstamped to denote a 0 or whether the cartridge simply was not marked at all. As a result, very little additional knowledge as to the unique identifier was added by the presence of the gear code. An example is shown in Figure 4, which is cartridge, number 233 (American Eagle). Optically, this cartridge was graded C2, although the better imaging available using the SEM allows the first three alpha-numerics to be read as T13 fairly easily, with suggestions of 2 additional identifiers, possibly a 5 or an S, and a 1. When examining the gear code the sectors for identifiers 3-8 are not visible at all; the first two sectors of the code yield the correct identifiers T and 1.

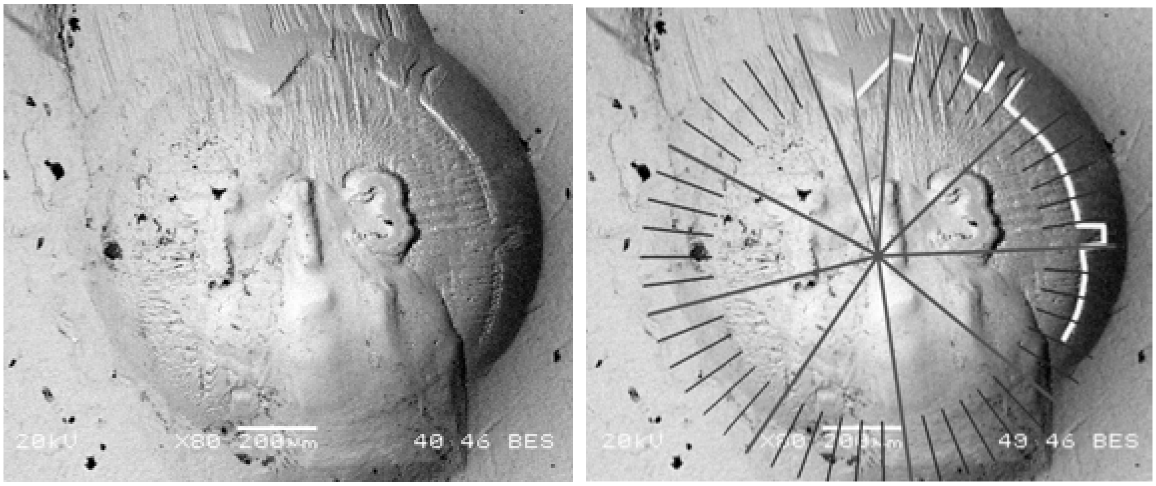

Figure 4: a) SEM image of Taurus cartridge #233, American Eagle. b) Outlined gear code and overlay.

In general for the Taurus cartridges examined, only the first two identifiers could be extracted from the gear code. Figure 5 shows an even poorer alpha-numeric and gear code transfer from cartridge #296 (American Eagle) graded C1 optically. Again the SEM imaging allows 1 and 3 to be ascertained from the alpha-numeric but only the number “1” is able to be deciphered using the gear code, which falls in the second sector of the eight possible sections. All other sectors appear distorted, precluding any interpretation with a high level of confidence.

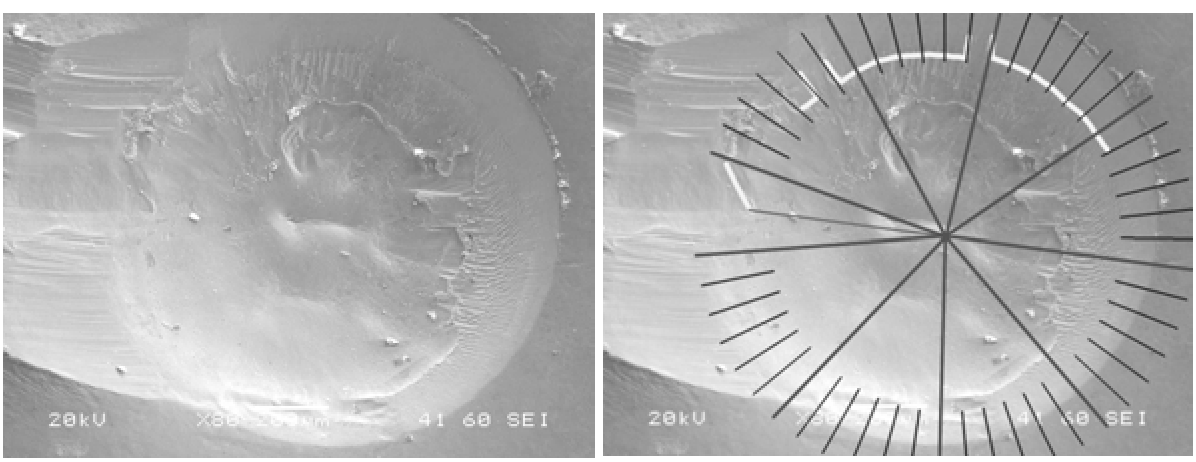

Figure 5: a) SEM image of Taurus cartridge #296, American Eagle. b) Outlined gear code and overlay.

Hi-Point

Like the Taurus, the Hi-Point did not transfer its gear code as well as the Sig Sauer. However, the Hi-Point pin did have a more robust gear code with considerable surface relief, which made it somewhat easier to discern if the primer had indeed been marked. In Figure 6, cartridge #610 (CCI Blazer) graded optically as C1 is shown. Again the SEM reveals more of the alpha-numeric than could be seen optically as well as a fraction of the gear code. In Figure 6a the identifier appears to be H60-PZ*, with the last alpha-numeric undistinguishable. When considering the gear code, "H" can be read clearly, but the "6" is slightly muddled. As the outline shows in Figure 6b, the gear code for the second identifier appears to read 000100, which would correspond to the number "4". This is obviously incorrect and forces an examiner to decide between what appears to be a clear marking of the alpha-numeric and the validity of the gear code.

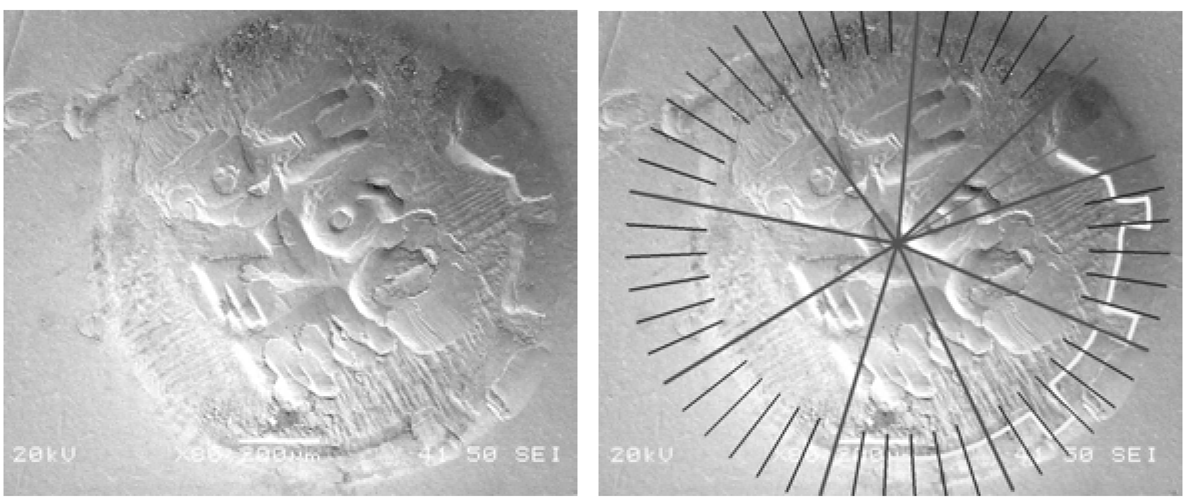

Figure 6: a) SEM image of a Hi-Point cartridge #610. b) Outlined gear code and overlay.

In this particular cartridge, the primer seems to have been struck twice and smeared, which distorts the alpha-numerics and obscures the correct gear code reading of (000110). Double strikes were especially prevalent in the Hi-Point.

A second example is shown in Figure 7. This Silver Bear cartridge, #520, was graded C0 optically. However, when imaged with SEM reasonable guesses could be made as to the identity of most of the alpha-numerics. Although there is considerable uncertainty and judgment involved, the identifier seems to be an H or an A, followed possibly by a 6, then 0. The second three-digit sequence appears to be possibly a P, followed by Z, then maybe a 5. In this case the gear code lends valuable assistance and permits unambiguous identification of the first two sectors, which translate as "H" and "6", confirming the tentative assessment of the image. The third sector almost reveals the third identifier as "0", but the last bit of the gear code didn't transfer. However, since most of the "0" did transfer on the identifier, an examiner might conclude that the first three digit sequence is H60.

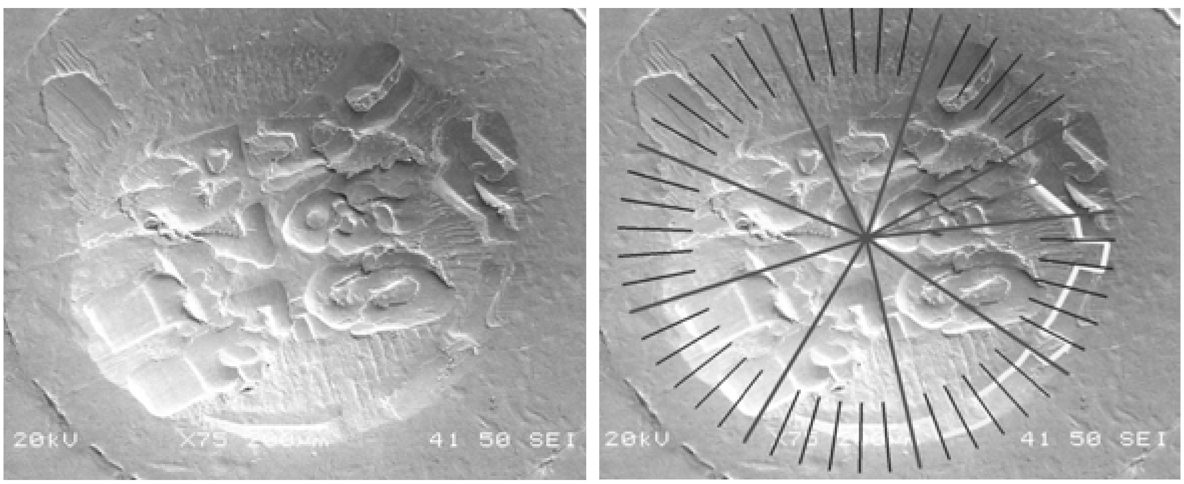

Figure 7: a) SEM image of Hi-Point cartridge #520, Silver Bear. b) Outlined gear code and overlay.

Like cartridge #610, cartridge #716 from the CorBon ammunition set also has an apparent erroneous gear code for the second digit. Optically, this cartridge was graded as C2, but three additional alpha-numerics are revealed through the SEM image. As seen in Figure 8, the first sector of the gear code reads correctly as 010001 (H), but again the second sector reads as 000100 (4). From the alpha-numerics that transferred, it's clear that the second alpha-numeric is actually a "6" and not "4" as the gear code suggests. The gear code corrects itself at the third sector and reads as 000000 (0). The gear code also correctly gives us the missing alpha-numeric, H, changing the overall clarity rating to C6. However, in a real-life setting the fact that the gear code does not match a corresponding clear alpha-numeric indicator casts doubt on any identification based on the gear code alone. Thus, while the entire code can be reconstructed, in all probability this identification would be disregarded as being unreliable. This instance points to a problem where an unclear marking of the gear code leads to a false interpretation.

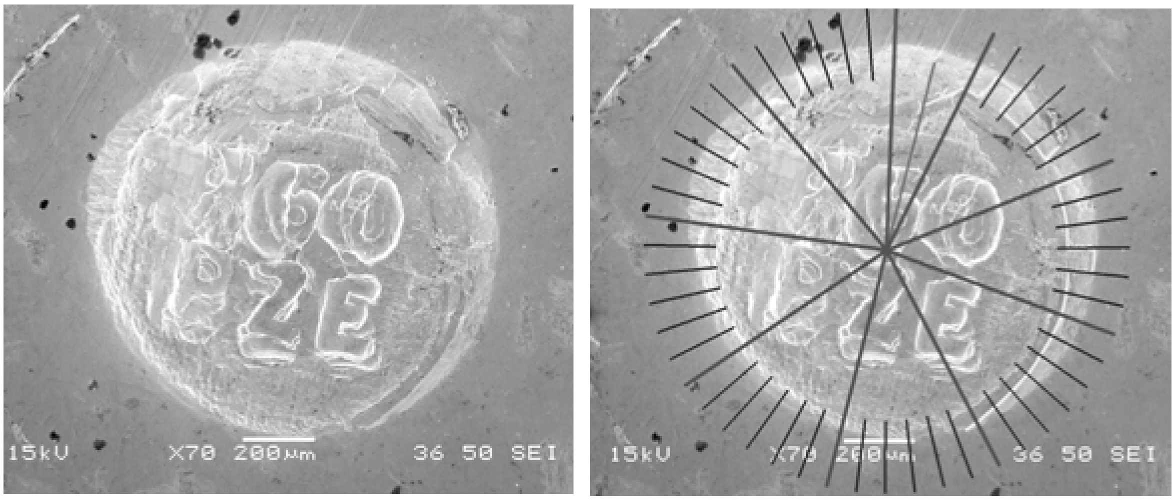

Figure 8: a) SEM image of Hi-Point cartridge #716, CorBon. b) Outlined gear code and overlay.

It is important to note at this point that the gear codes on the firing pins used for #610 and #716 are correct and that the error is introduced during the marking. Examination of both #610 and #716 using SEM show that both cartridges appear to have been double-struck. This presumably is the reason for the apparently erroneous gear code markings.

Lacquered Cartridges

Lacquered cartridges, from the Sellier & Bellot ammunition, posed problems during the optical and SEM evaluations, especially for the Hi-Point cartridges as it interfered with the transfer of the identifiers and the gear code. As seen in Figure 9, Sig Sauer cartridge #909 (S&B) does not have the clarity that the earlier cartridges did in either the alpha-numeric characters or the gear code. In fact, the only parts of the gear code that can be readily deciphered are the first and last sections, both of which read 011001 (S).

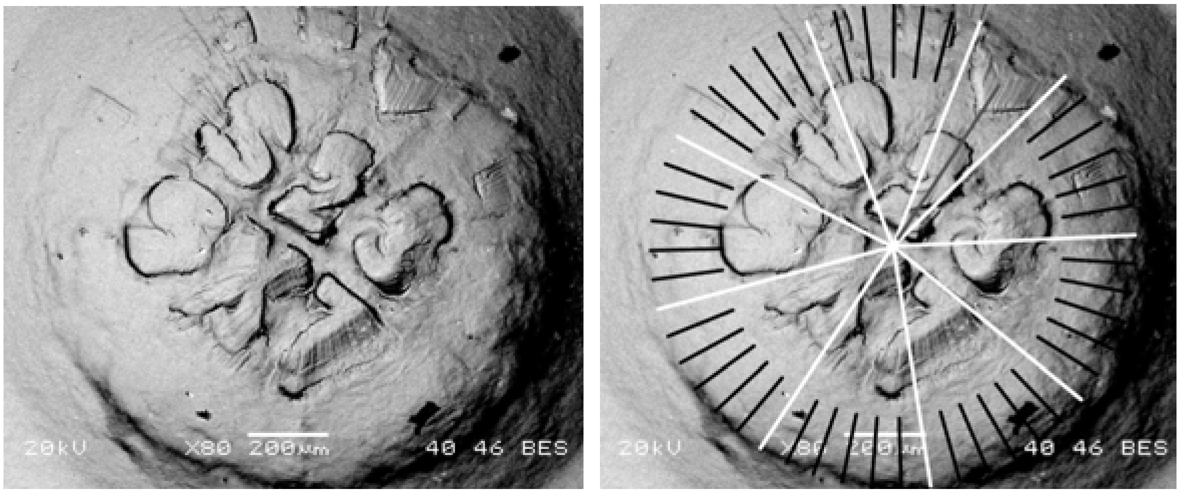

Figure 9: a) SEM image of Sig Sauer cartridge #909, S&B. b) Outlined gear code and overlay.

The slightly smeared Sig Sauer transfer described above still appears fairly clear, however, especially when compared to the poorest transfers from some of the Hi-Point cartridges. Figure 10 is a good example of some of these transfers. Hi-Point cartridge #974 (S&B) in Figure 10a was graded optically as C0 and its grade only improves to C1 with SEM and gear code analysis. By comparison, the gear code on cartridge 937 did not fare as well as that of 974. The first half of the visible portion is wiped out, making any analysis of the gear code futile. However, the SEM analysis does yield another alpha-numeric character than the optical grade did, making the total clarity rating C2.

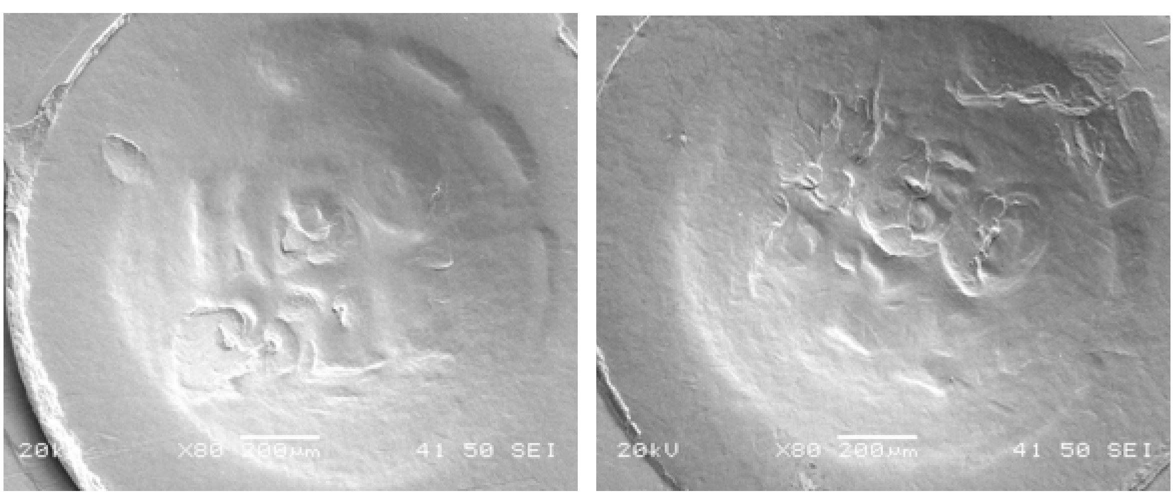

Figure 10: a) SEM image of HP cartridge #974. b) SEM image of HP cartridge #937.

Like the unlacquered cartridges, the lacquered Taurus cartridges showed poor gear code transfer, even to the extent of lacking the starting wedge marker (Figure 11). Though the lacquer smeared the alpha-numerics of the Hi-Point extensively, the Taurus did not exhibit such extreme distortion. As evidenced by Figure 11, the alpha-numerics are still legible. Cartridge #945 (S&B) shown in Figure 11a was graded optically as C3 and with SEM evaluation the total clarity grade conservatively becomes C4 and it could be argued a C6. Cartridge 944 was graded optically as C2, but all 6 alpha-numerics are visible in the SEM image.

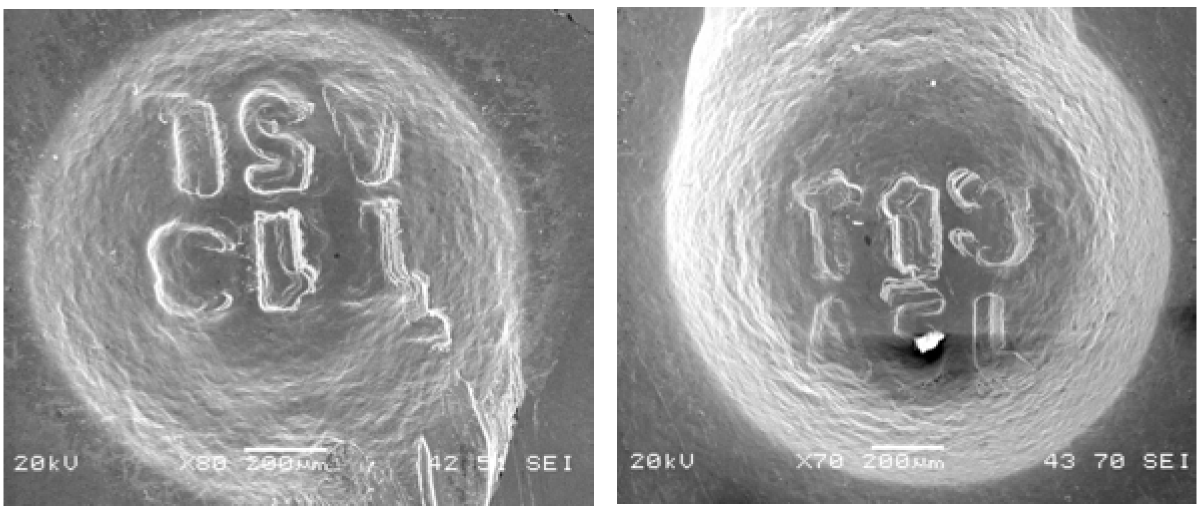

Figure 11: a) SEM image of Taurus cartridge #944. b) SEM image of Taurus cartridge #945.

Gear Code Analysis by Magazine

Often where a shooting has occurred several cartridge cases may be left behind. Assuming that the gun used was equipped with a microstamped firing pin, one argument made in defense of compiling, or adding, partially transferred markings is that given a large number of incompletely marked cartridges from (presumably) the same firearm, could the entire identifier be reconstructed? An analogy would be that part of an automobile license plate is better than no plate number at all. To examine this hypothesis, cartridges from two magazines from each gun were examined optically with a stereomicroscope, one from a non-lacquered ammunition set and the other from the lacquered S&B

cartridges. Each magazine chosen had the highest number of non-C6 ratings to represent a possible worst case scenario. Table III summarizes the grades of the chosen magazines. The bold, capital X's denote both the alphanumeric character and its corresponding section of gear code were legible, the lower case, x's denote only the alphanumeric character having a clear transfer and GC denotes only the gear code being decipherable. If the table is blank it means for that cartridge neither the alpha-numeric or gear code were decipherable.

Not surprisingly, the only complete alpha-numeric + gear code transfers occurred in the Sig Sauer, both unlacquered and lacquered. It should be noted, however, that due to the presence of lacquer in cartridges 901-1000, the transferred gear code was slightly smeared, but the code in many cases could still be deciphered.

The Taurus cartridges again did not have all of the gear code on the unlacquered cartridges, though they did assist in identifying the first one or two alphanumeric identifiers. The lacquered Taurus cartridges were largely unhelpful in examining the gear code. The Taurus firing pin's lack of surface relief combined with the lacquer coated primers caused no gear code transfer in the Sellier & Bellot cartridges. In some cases, even the start wedge of the gear code failed to transfer.

The Hi-Point gear codes were slightly more helpful than those of the Taurus. Still, the gear code transfer did not extend beyond the "0," and as evidenced by the table, in several cases did not transfer or did not transfer legibly.

Despite the poor performance in some cases, it is still apparent that if one knows or could safely assume that all ten cartridges found at a crime scene came from a single clip of ammunition, the entire identifier could be reconstructed using the combined information for every magazine examined in this study.

Table III: Summary of gear code and alphanumeric character evaluation from low grade clips

Hi-Point														
	Unlacquered								Lacquered (S&B)					
Ctg.	H	6	0	P	Z	E		Ctg.	H	6	0	P	Z	E
571	**X**	**X**	**X**	x	x	x		981	**X**	**X**	**X**		x	
572	**X**	**X**	x	x	x			982	x	x			x	
573		**X**		x	x			983	x	x			x	x
574		x	x		x	x		984	GC	x	x		x	x
575	x	x	x					985	GC	x	x			x
576	x		x	x	x			986	GC	**X**	**X**	x		
577	x	x	x	x	x	x		987	x		**X**	x	x	x
578		**X**	**X**	x		x		988	**X**	**X**	**X**	x	x	x
579		x			x	x		989	GC	**X**	**X**		x	x
580	x	x	x	x	x	x		990	x					
Taurus														
	Unlacquered								Lacquered (S&B)					
Ctg.	T	1	3	A	5	L		Ctg.	T	1	3	A	5	L
571	**X**	x	x	x	x	x		911	x	x	x	x	x	x
572	**X**	**X**	x	x	x	x		912		x	x	x		x
573	**X**	**X**	x		x	x		913	x	x	x	x	x	x
574	**X**	**X**	x	x	x	x		914	x	x	x	x	x	x
575	x	x	x	x	x			915	x	x	x	x	x	x
576	**X**	x	x		x	x		916	x	x	x	x	x	x
577	**X**	**X**	x	x	x	x		917		x	x	x	x	x
578	**X**	**X**	x	x	x	x		918	x	x	x	x	x	x
579	**X**	**X**	x	x	x	x		919		x	x	x	x	x
580	**X**	x	x		x	x		920	x	x	x		x	
Sig Sauer														
	Unlacquered								Lacquered (S&B)					
Ctg.	S	2	3	S	X	7		Ctg.	S	2	3	S	X	7
191	**X**	**X**	**X**	**X**	**X**	**X**		911	**X**	x		x	x	
192	**X**	**X**	**X**	**X**	**X**	**X**		912	**X**	**X**	**X**	**X**	**X**	**X**
193	**X**	**X**	**X**	**X**	**X**	**X**		913	x	**X**	**X**	**X**	**X**	**X**
194	**X**	**X**	**X**	**X**	**X**	**X**		914	x	x	x	x	x	x
195	**X**	**X**	**X**	**X**	**X**	**X**		915	**X**	**X**	x	x	**X**	**X**

Table III (Continued)

	Unlacquered								Lacquered (S&B)					
Ctg.	S	2	3	S	X	7		Ctg.	S	2	3	S	X	7
196	**X**	**X**	**X**	**X**	**X**	**X**		916	**X**	**X**	**X**	**X**	**X**	**X**
197	**X**	**X**	**X**	**X**	**X**	x		917	**X**	**X**	x	x	x	x
198	**X**	GC	**X**	**X**	GC	**X**		918	x	x	x	x	x	x
199	**X**	**X**	GC	x	GC	GC		919	x	x	x		x	x
200	**X**	**X**	**X**	**X**	**X**	**X**		920	x	x	x		x	x

Discussion

A summary of the results obtained in this study is shown in Table IV for the 26 cartridges examined. As seen in the table, simply using the SEM as an evaluation tool measurably increased the number of visible alpha-numerics, irrespective of the gear code. In fact, the gear code was only seen to increase the number of identifiable alpha-numerics in a single instance, although it could be argued perhaps that the gear code did confirm the guesses made based on SEM imaging. However, this help must be balanced with those cases where the gear code seemed to be at odds with the visual data from imaging (e.g. cartridges H610 and H716).

Table IV: Summary of grades from optical and SEM assessments.

Sig Sauer					
Ctg. Number	**Brand**	**Optical grade**	**SEM grade**	**Gear Code**	**Total Identifiers**
10	Brown Bear	C1	C3	C5	C6
24	Brown Bear	C2	C6	C6	C6
707	CorBon	C0	C2	C2	C3
908	S&B	C0	C2	C1	C2
909	S&B	C5	C6	C2	C6
965	S&B	C4	C4	C0	C4
985	S&B	C4	C6	C0	C6
Taurus					
Ctg. Number	**Brand**	**Optical grade**	**SEM grade**	**Gear Code**	**Total Identifiers**
101	DAG	C5	C6	C0	C6
233	Amer. Eagle	C2	C3	C2	C3
275	Amer. Eagle	C5	C5	C0	C5

Table IV (Continued)

282	Amer. Eagle	C2	C3	C0	C3
296	Amer. Eagle	C1	C2	C1	C2
944	S&B	C2	C6	C0	C6
945	S&B	C3	C4	C0	C4
Hi-Point					
Ctg. Number	**Brand**	**Optical grade**	**SEM grade**	**Gear Code**	**Total Identifiers**
164	DAG	C1	C6	C1	C6
218	Amer. Eagle	C2	C3	C0	C3
420	PMC	C2	C6	C3	C6
520	Silver Bear	C0	C3	C2	C4
541	Silver Bear	C1	C5	C0	C5
573	Silver Bear	C2	C6	C3	C6
610	CCI Blazer	C1	C5	C1	C5
716	CorBon	C2	C5	C2	C6
880	Independence	C2	C6	C3	C6
910	S&B	C2	C4	C0	C4
937	S&B	C1	C2	C0	C2
974	S&B	C0	C1	C1	C1

As mentioned, most of the improvement in scores came not by use of the gear code but by the improved imaging characteristics of the SEM. While this is encouraging, the SEM may not be readily available to forensic examiners. It is interesting that the majority of the gear codes tended to mark well in the initial sectors (e.g. up to the first three identifiers, especially with the Hi-Point and Taurus) but less well in the remaining ones. Unfortunately, the code in the missing regions often corresponded to the missing alpha-numerics, so the gear code rarely was able to clarify any uncertainties in the last three alpha-numerics. For the evaluated cartridges, the clarity of the transferred alpha-numerics as a function of position was examined to see if any trends existed that might guide placement of the gear code in such a manner as to better allow reconstruction of the missing alpha-numerics using the gear code, such as possibly a reversal of the gear code to run counter-clockwise rather than clockwise. While no clear trends were discernible from the limited amount of data obtained this remains an area worth investigating. If the firing / ejection mechanism of a particular handgun consistently produces a smearing of the alpha-numeric in a certain area, it might be possible to design the gear code such as to provide redundancy in an area that statistically provides good transfer clarity. Other possible areas to study include the effect of the shape of the firing pin as pertaining to size and radius of curvature at the tip; the average force exerted on the firing pin; and the effect of striker vs. hammer, etc. All these variables can be expected to play a role in the quality of transfer. While the cycle of fire protocol used to place the unique identifier on the firing pin ensured that the best possible transfer was achieved for the given set of conditions associated with that particular firearm, it does not identify the particular variable and/or define the optimum parameters in firearm design / manufacture that would ensure the best transfer of the alphanumeric and gear code. Such a study might also be worthwhile.

It should also be noted that the quality of the gear code transfer was not examined in cartridges that previously had received a rating of C6. Since the gear code is meant to be a backup for those who might seek to remove the alpha-numeric code at the tip, this also is an area of further study. A study of determining the identifier based solely on the gear code is planned for the future.

Conclusions

This study investigated the transfer of a digital circumferential gear code placed on the end of the firing pin of three different firearms. As seen in a previous study that only evaluated the quality of alpha-numeric transfer, this study showed that gear code transfer was not universal. However, with partial information from both the identifiers and the gear code, some identification can be made, especially when the information discernible from the gear code does not overlap that provided by the readable alpha-numerics. That being said, a full gear code appears to be rare and dependent on the weapon that made the impression. Also problematic was the gear code appeared to be at odds with the alpha-numeric in certain instances. While the latter appears to be related to double strikes, which can be recognized by an examiner, the former problem requires more study concerning exactly what combination of type of mechanism / pin / action / minimum pressure etc. is most likely to produce good transfer.

While large pieces of the gear code did not transfer in many cases, SEM evaluation greatly improved the clarity ratings for nearly all selected cartridges. This suggests that simply equipping labs with small, relatively inexpensive SEMs (simple models can be had for ≈ 50K) may be more cost effective than extensive research and development of improved gear code transfer.

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CHAPTER 5. SUMMARY AND CONCLUSIONS

The comparison of plier data with the statistical algorithm revealed the algorithm is more robust than previously thought. Using parameters that were successful in evaluating evenly striated screwdriver marks proved inconclusive when applied to the quasi striated marks of the pliers. Further experiments varying the window size ratios proved more successful in separating the known match and known non-match comparisons. Some incorrect match identifications were made by the algorithm and were termed “opposite end” matches. Future work with this algorithm will include a feature to detect when this has occurred and alert the user.

From the microstamp evaluation study, three different guns equipped with microstamped firing pins were used to fire 1000 cartridges each. Ten different brands of ammunition were used to examine the difference between primer hardness and the transfer quality of the microstamp. The fired cartridges were evaluated for clarity of transfer by a trained examiner and a novice using a stereomicroscope. Some differences in clarity were observed, which could not be attributed to the examined variables: primer material, primer hardness, Boxer vs. Berdan primers, or cartridge material. However, a noticeable drop in clarity ratings occurred with the lacquered cartridges, as the lacquer interfered with the microstamp transfer. The most notable difference in quality of transfer occurred when comparing the weapons. The Sig Sauer had the best transfer of both alphanumeric and gear code, while the Hi-Point had the worst alphanumeric transfer but more gear code present than the Taurus.

While the microstamp study primarily evaluated the alphanumeric identifier transfer, the gear code study sought to assess the quality and legibility of the circumferential code surrounding the alphanumerics on the microstamped cartridges. From this examination, the gear code transfer was not universal. However, partial information from the gear code can be acquired. Complete gear code transfer appears to be rare and entirely dependent on the weapon that made the microstamped impression. The Sig Sauer had the best and most complete gear code transfer, while the Taurus gear code was sparse. Additionally, in nearly all of the examined cases, SEM evaluation improved the clarity ratings of the alphanumeric transfer.

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