Ronald G. Nichols,[1] *B.S.*

Firearm and Toolmark Identification Criteria: A Review of the Literature

REFERENCE: Nichols RG. Firearm and toolmark identification criteria: A review of the literature. J Forensic Sci 1997; 42(3):466–474.

ABSTRACT: A review of the literature pertaining to identification criteria for firearms and toolmark identification was performed. Thirty-four articles were reviewed including empirical studies of consecutively manufactured barrels, firing pins, breechfaces, and assorted tools. Also reviewed were mathematical and computer models developed for the purpose of developing a standard identification criteria. These articles are reviewed in a format to allow interested parties to learn what has been done in the field so as to permit a better articulation of their own criteria for identification.

KEYWORDS: forensic science, criminalistics, firearms, toolmarks, identification criteria

In 1984, Biasotti and Murdock published an article in which they discussed state-of-the-art for firearm and toolmark identification (1). This article addressed several different areas, but they all related to the topic of establishing a criteria for identification and whether the criteria was subjective or objective.

They discussed the impact of various tool manufacturing methods on the individuality of marks produced by tools. They discussed the concepts of class characteristics which are intentional; sub-class characteristics which are unintentional but common to a select group; and individual characteristics which are accidental and unique. They cite John Davis as the first individual to discuss in detail the concept of sub-class characteristics.

They also discussed the benefits and drawbacks of three different types of studies: Empirical studies; mechanical models, and mathematical models. Empirical studies were deemed to have much benefit for the individuals actually taking part in the study. However, due to the subjective nature of comparisons, any studies that did not document the examination in more objective ways were very difficult for other examiners to utilize. Some studies did do a statistical analysis and were of somewhat more use to others in the field. Mechanical models were designed to assess the correspondence that one could expect to find in two different marks based solely on chance. An example of this is sand paper on photographic paper. Mathematical models are attempts to objectively assess subjective data.

Two important concepts were discussed. The first was the concept of consecutively matching striae. This was the premise for an article by Biasotti which will be discussed later. The second concept dealt with the criteria for identification. Essentially, such criteria is that amount of correspondence between two items that exceeds the amount of correspondence in a known nonmatch. Inherent in this correspondence is quality and quantity of marks. They discuss each.

In summary, Biasotti and Murdock make recommendations for the expert in firearms identification. They include familiarity with empirical studies, mechanical and mathematical models, different manufacturing methods and their impact on individuality, and the extent of agreement in known non-match situations. The latter is gained through arduous hours of comparative microscopy. They also concede that criteria for identification is subjective but that they hold some hope for objectivity in the future.

This paper is an attempt to bring together as many of the different articles that have dealt with establishing some criteria for identification as is possible. This includes many empirical studies on the comparison of bullets, casings, and toolmarks. In addition, there are mathematical and computer models cited which attempt to provide a more mathematical basis for identification. Throughout the diversity of articles, there is a quest, whether stated or not, for some criteria for identification that is meaningful to the field of firearm and toolmark examiners.

Empirical Studies

Empirical studies have been performed since the early part of the century and easily represent the bulk of the material in this quest for identification criteria. Unfortunately, most of these studies are very subjective in nature and as a result, only lend fuel to the "subjective" fire. Yet, most of these studies appear to have been carried out in a manner analogous to the scientific method and as a result, do have some useful information. Included among these empirical studies are those dealing with bullets and barrels, cartridge casings, and other toolmarks. They have been compiled in those categories.

Bullets and Barrels

In 1949, Churchman published a study that discussed characteristics that were discovered to be fairly typical of Cooey, .22 caliber rifle barrels (2). Churchman emphasized the importance of knowing the origin of markings on bullets before one could utilize them for the purposes of unequivocal identification. Although he did not refer to them as such, the broaching technique used to rifle the Cooey barrels was responsible for producing sub-class characteristics. Churchman went into a detailed description of broach rifling.

In addition, Churchman classified three types of characteristics which are still in existence today in one form or another. "C" type characteristics were defined as class characteristics. "A" type

[1] Criminalist III, Oakland Police Department Criminalistics Laboratory, Oakland, CA.

Received 9 July 1996; accepted 9 Sept. 1996.

characteristics were defined as accidental characteristics, i.e., individual characteristics. "B" type characteristics were defined as broach series characteristics. These are essentially sub-class characteristics. In this particular instance, Churchman referred to them with respect to the broached, Cooey rifle barrels. "B" type characteristics were subdivided into two different types, B1 and B2, both of which occur on the edges of land impressions. This was not critical. What was critical was a recognition that these sub-class characteristics do occur and a search for the reason why. This is how one formulates a criteria for identification.

Churchman examined test fired bullets from three consecutively broached, .22 caliber rifle barrels manufactured by Cooey. He found correspondence of "B" type characteristics, i.e., sub-class, persisting from barrel to barrel. However, there was significant disagreement in "A" type characteristics which were located across the central portion of the land impression.

In 1959, Biasotti published a summary of a statistical study that he performed beginning in 1955 (3). This study was prompted by the near lack of any published "factual and statistical data pertaining to the problem of establishing identity in the field of firearms identification. . ." Biasotti's study was a very intensive statistical evaluation of the individuality of bullets fired from different firearms.

Biasotti used a total of 24, .38 SPL, Smith & Wesson revolvers for the study. Sixteen of these were in well-used condition whereas the remaining eight were new. Group I consisted of the 16 used revolvers each firing six 158 grain solid lead bullets. For each revolver, the second through sixth test fires were intercompared versus the first test fired bullet. Each land impression was compared versus each land impression, and each groove impression was compared versus each groove impression. In total, 400 land impression combinations and 400 groove impression combinations were evaluated. Group II consisted of the eight new weapons each firing six 158 grain solid lead bullets. These were evaluated in the same manner as those in Group I. In total, 200 different land impression combinations and 200 different groove impression combinations were evaluated for Group II. Group III consisted of the same new weapons used in Group II firing six 158 grain jacketed bullets. These bullets were evaluated in the same manner as those in Groups I and II. In total, 200 different land impression combinations and 200 different groove impression combinations were evaluated for Group III. In addition, for each group, the first test fired bullet for each weapon was compared versus the first test fired bullet of each of the other weapons. In total, there were 36 different combinations with 180 land impression combinations and 180 groove impression combinations.

Biasotti evaluated the different impression combinations for percentage of matching striae and consecutiveness. In order to do this, he defined two terms which are of some significance. The first is "line" which he equated to "striation." "Line" was defined as "an engraving or striation appearing on the bullet as a result of being engraved by the individual irregularities of characteristics of the barrel, plus any foreign material present in the barrel capable of engraving the bullet." These lines would be continuous and well defined. Biasotti also defined "consecutiveness" as "the compounding of a number of individual characteristics" and as a "simplified means of expressing correspondence of contour." He evaluated not only quantity (an objective feature), but also quality (a subjective feature).

His results are not particularly news to us now, although they may have made some examiners disconcerted at the time. The average percentage of matching lines in jacketed bullets fired from the same gun was 21–24%. He frequently encountered 15–20% matching striations on land or groove impressions between bullets fired from different weapons. Quantity alone would certainly not provide one with an identification.

When Biasotti evaluated the consecutiveness, he readily stated that he was more conservative in calling matching lines for bullets fired from the same weapon and very liberal in calling matching lines for bullets fired from different weapons. Even so, Biasotti could not find more than three consecutive matching striae for lead bullets fired from different weapons. This incorporated 360 different land impression combinations and 360 different groove impression combinations. For the jacketed ammunition, he could not find more than four consecutive lines for bullets fired from different weapons. This incorporated 180 different land impression combinations and 180 different groove impression combinations.

To date, this stands as the most exhaustive statistical empirical study ever published. There are indications Biasotti hoped that this would lead to more studies in an effort to make the criteria more objective. His other hope, i.e., that it would provide a basis for mathematical models, came to fruition later.

In 1970, Lutz published one of the first studies on the correspondence of markings on bullets test fired from consecutively rifled barrels (4). His study involved two unused .38 SPL barrels. Even though it had not been indicated in the article, it was learned later that the barrels had been rifled using the broach technique. This study was a practical study in that it focused on the examiner's ability to distinguish bullets fired from two different barrels.

Lutz fired a series of lead and jacketed bullets through each of the two barrels. These formed the test sequence and they were appropriately marked. He then fired a second set of bullets through each barrel and had these coded. Examiners then compared the coded bullets versus the known test fired specimens. The paper was accompanied by photomicrographs but was essentially a compilation of subjective observations. Lutz indicated that the examiners were able to "easily identify the barrel of origin for each of the bullets." In addition, when each land impression on the bullets from one barrel were compared versus each land impression on the bullets from the second barrel, there were "many dissimilarities."

No mention was made of the correspondence of the groove impressions. For broach rifled barrels, it is expected that the groove impressions would demonstrate the most correspondence because it is on the groove impressions that one can expect to find sub-class characteristics.

In 1975, Skolrood published a study that was similar to that of Churchman's earlier work (5). Skolrood wished to know whether the observations and conclusions reached by Churchman were still valid after Cooey was absorbed by Winchester. He obtained three new, consecutively broached, .22 caliber rifle barrels. He performed a series of intercomparisons between bullets fired from the same barrels as well as comparisons between bullets fired from different barrels.

Comparisons of bullets fired from the same barrel demonstrated acceptable correspondence of accidental characteristics. For the comparisons of bullets fired from different barrels, Skolrood observed, "No 'carry-over' of pertinent characteristics was noted from one barrel to another, other than class characteristics." He did note in these comparisons that the broaching characteristics observed and reported by Churchman were also present in these three barrels. Obviously, "pertinent characteristics" must refer to accidental characteristics.

In 1978, Freeman published a study involving three consecutively rifled, Heckler & Koch, 9-mm luger caliber, polygonally rifled barrels (6). Initially, five 115 grain, full metal jacketed bullets were fired through each of the three barrels. Markings on the sets from the first two barrels were of sufficient quality such that they could be easily intercompared. Test fired bullets from the third barrel consistently marked poorly even with different ammunition.

The paper focused primarily on the difficulty in obtaining quality markings on bullets from the third barrel, the comparison of bullets fired from the same barrel and the fluting marks present on bullets fired from such barrels. There was very little concerning the actual comparison of bullets fired from different barrels, except to say that the test results showed agreement with earlier studies that "each barrel has a distinct and separate individuality." Even the photographs that were provided depict comparisons of bullets fired from the same barrel.

In 1981, Murdock published an extensively researched paper regarding gun barrel individuality and an empirical assessment of the individuality of button rifled barrels (7). He began by citing the works of Goddard who credited Balthazard with making the significant contribution to bullet identification, that is, each barrel is unique. Murdock continued by discussing the early theory behind gun barrel individuality. This early theory was based upon the early methods of rifling, i.e., cut rifling. Murdock's goal was not to refute this theory, but with the advent of newer, swagging methods of rifling, Murdock felt that the "concept of the individuality of cut rifled barrels promoted by pioneers in the firearms identification field could not be transferred unilaterally to button rifled gun barrels."

Murdock gives in-depth treatment to the various forms of early cut-rifling methods: Scrape cutter; hook cutter; and gang broach. He discusses that common features of all three as well as their own unique characteristics. He remarked that these methods of rifling typically left sub-class features on multiple barrels. These sub-class features are unintentional features, subsequent to manufacture, that a group of items may possess. He remarked that it is for this reason that examiners rely more heavily on the uncut lands areas of the barrel for their identification.

Murdock also discussed three methods of rifling that do not involve the removal of any metal but are accomplished through a swagging process. Essentially, metal is pushed out of the way and formed. The three methods he discussed are button, mandrel, and hammer forging. Murdock felt a need to assess the individuality of the swagging method because it did not involve the removal of any metal, something upon which the early concepts of individuality were based.

Murdock assessed the individuality of sequentially button rifled, .22 caliber barrels. He obtained three consecutively button rifled barrels from three different manufacturers. He fired ten solid lead bullets through each. For each set of barrels, he intercompared test fired bullets fired from the same barrel and compared test fired bullets fired from different barrels. He did note that the first three bullets fired from each barrel could not even be identified to each other. For his comparisons of bullets fired from different barrels, Murdock compared every land impression versus every land impression and every groove impression versus every groove impression. He did not note any significant correspondence including the presence of any sub-class characteristics.

In 1983, Hall of Canada performed a study of consecutively button rifled barrels with polygonal rifling (8). The four barrels were Shilen DGA barrels. Two of the barrels were consecutively reamed after drilling. Two others were selected at random after the reaming process. These four barrels were then consecutively rifled using a button. A total of 31 bullets were fired from each barrel. In this study, Hall wished to examine other factors (in addition to different barrels) to determine their effect on the identifiability of the bullets.

Halls' work appeared to be hampered in part by the poor overall quality of the markings on the test fired bullets. When attempting to intercompare test fired bullets from the same barrel, Hall observed phenomena that had been earlier reported. This included individual markings constantly changing on the first few bullets fired from a new barrel such that they could not be identified. Test fired shots closer in firing sequence showed more correspondence than test fired shots further apart in the firing sequence. For these reasons, when Hall compared bullets from different barrels, he compared those bullets which had the same firing sequence numbers from their respective barrels.

Hall did not appear to compare every land impression versus every land impression combination. Rather, he was able to phase on the top land impression for each barrel through a combination of indexing and ejector port markings. In addition, there was a gross mark which did carry over from barrel to barrel which became more distinct as the test firing progressed. As a result of his comparisons, Hall was able to conclude that, "With bullets closely related in the firing sequence the dissimilarity of marks created by any two different barrels is significantly greater than the dissimilarity seen on bullet pairs that are from the same barrel."

In 1985, William Matty published a study of the individuality of three revolvers barrels all cut from the same section of rifled tube (9). This certainly does appear to be on the verge of a worst case scenario. Up to this time, studies involved barrels which were individually rifled. For this study, one long tube was rifled and then sectioned into three barrels. Matty had observed that the buttons used to rifle barrels do acquire some damage. He was interested in how well this damage was transferred to the bore surface and how long this would persist.

Matty performed comparisons of Mikrosil casts of the barrels prior to firing any bullets. He then performed intercomparisons of bullets fired from the same barrel and comparisons of bullets fired from different barrels. When comparing Mikrosil casts, he observed no significant carry-over of markings on the land impressions. However, he did observe numerous longitudinal striations on the groove impressions that were caused by button imperfections. A few of these persisted along the length of all three barrels.

When Matty compared bullets fired from the same barrel, he observed what others had already reported. There was a settling-in period during which test fired bullets from the same barrel could not be identified to each other. The bullets demonstrate a rapid change in characteristics on the land impressions such that an identification was not possible if one had to rely on the land impressions alone.

Comparisons of bullets fired from different barrels were conducted after the settling-in period. In the groove impressions, there was, "Sufficient carry-over for phasing but not enough for a conclusive identification. The land impressions, not surprisingly, bore no consistency in markings."

In 1992, Dave Brundage from the Illinois State Police conducted a study to determine whether trained firearms examiners could correctly associate bullets with the barrel that fired them (10). Brundage acquired ten consecutively rifled barrels from Ruger and provided a pair of test fired bullets from each to 30 laboratories across the country. He also provided each of these 30 laboratories with 15 unknowns, at least one from each of the ten barrels.

Examiners from each of these laboratories were asked to associate the unknowns with the appropriate barrel from which they were fired based upon comparison versus the known test fired bullets. All properly associated the unknowns with the barrel from which they were fired.

The purpose of this study was to eliminate the anomalies Brundage felt were present in other studies conducted to date. None of the examiners across the country had any information regarding barrel or test manufacture unlike authors of previous studies.

In 1995, Brown and Bryant published a study in which they compared barrels from multi-barreled derringers in an attempt to determine whether the barrels in these weapons may have been consecutively manufactured (11). This study, like many others dealt with concepts of class, subclass and individual characteristics. In their article, the authors referred to subclass characteristics as "class type" striations.

In their examinations of multi-barreled derringers, they discovered that several had barrels which appeared to have been manufactured very closely in line with the other barrel in the weapon. One derringer had matching groove impressions, but "no matching striation patterns on the bullet land impressions." It was not stated as such in the article, but the term "matching striation pattern" may refer to consecutiveness as described by Biasotti. Other derringers had barrels which demonstrated some matching striation patterns near the muzzles of their respective barrels. However, these patterns were not transferred to the bullets fired through them.

The authors indicate that, "A major contributor to the individual bullet striae from the button rifled barrels is certainly the compressed reamer marks that appear very prominently in the casts of the lands and grooves." These marks run perpendicular to the rifling and, as a result, transfer as individual markings to the surface of bullets fired through them and certainly would not be expected to produce sub-class characteristics.

Cartridge Casings

In 1984, Matty and Johnson collaborated on a study of consecutively manufactured firing pins (12). These firing pins were designed for mounting in the Smith & Wesson K-frame. They fully describe the lathe turning operation which was used to manufacture the firing pins. Such an operation causes the surface of the firing pins to have concentric circles. It was desired to assess the individuality of firing pins produced by such an operation.

They compared the markings by direct comparison, lead impressions, and fired casings. They observed that the markings were persistent and that coarse and fine lines could be matched between different firing pins. They concluded that in addition to these circular marks, it was necessary to have random marks for an identification. Such marks would include pitting, scratches, and other damage acquired subsequent to their manufacture.

In the same year, Matty published a study which assessed the individuality of consecutively tooled Raven breechfaces (13). He began by describing in-depth the milling process used to surface breechfaces by Raven Arms for their .25 AUTO semi-automatic pistols. Such a process causes the surface to have concentric circles on the breechface. Raven provided him with a total of six bolts. These were consecutively tooled. One hour later in the manufacturing process, three additional consecutively tooled bolts were selected. Comparison of the six bolts demonstrated that while each could be identified to itself when offset by 180°, there was no significant correspondence between different breechfaces.

In 1986, Tsuneo Uchiyama published a study in which he did an extensive set of comparisons between breechface markings produced by weapons with close serial numbers (14). As is well known, consecutive serial numbers does not necessarily correlate to consecutively manufactured firearms. Even though there is no confirmed consecutiveness of weapons in this study, it is still very valuable. It contains an extensive amount of known nonmatch comparisons that are photographically documented. In addition, it concentrates on .25 AUTO caliber pistols. These pistols typically leave relatively poor markings on the breechfaces. Therefore, even if the bolts demonstrate wide marking variability from bolt to bolt, such variability may not be evident on the fired casings because of the few marks actually impressed during firing. For his work, Uchiyama selected five .25 AUTO Browning pistols with straight breechface markings and 24 .25 AUTO Raven pistols with concentric circular breechface markings.

Uchiyama presented photographs of both known matches and known nonmatches. The photographs documented very well what was observed. For the known nonmatches, there was some significant correspondence of the coarser markings. In addition, because few of the concentric circular marks were actually impressed on the expended casings, it could be very difficult to exclude all but one firearm as having produced those markings.

Uchiyama discussed identification criteria. Even though he would like to see some sort of objective criteria, he stated that, ". . . it is impossible to set one criterion to distinguish between matched and unmatched pairs, because in some cases the number of matched lines is rather small even when they were fired from the same gun." Certainly it would be inappropriate to require five matching features or 50% matching features when a particular item may have only two to begin with! In conclusion, Uchiyama stated that, "The conclusion of comparison should be rated by probabilistic scaling."

In 1994, Thompson published a study very similar to Matty's study on breechfaces of Raven firearms (15). Thompson was motivated by a similar desire that motivated Skolrood in 1975. The manufacturer had changed, i.e., Raven to Phoenix, and Thompson was interested in whether or not this would impact the observations and conclusions of Matty's earlier work. For his study, Thompson acquired four bolts which were randomly selected from a batch of 60,000. Each was milled and had concentric circular markings on their breechfaces.

Thompson compared Mikrosil casts as well as fired casings. The breechfaces could be distinguished without a problem when working with the Mikrosil casts. However, the markings were not well impressed on the test fired casings. As a result, when he compared test fired casings marked by different bolts, he was not able to exclude any of the four bolts as having produced the markings on any of the four casings based upon the concentric circles alone. This observation was important in that it confirmed the need to look at not only the situation theoretically, but also in a practical manner as well. Practically, one would not need to compare different bolts. One does compare different casings. It is very useful when a study can provide some practical application.

Lardizabal reported in 1995 of correspondence observed on breech faces of Heckler & Koch, .40 S & W caliber pistols (16). Lardizabal encountered three different such pistols, two with sequential serial numbers and one with a lower serial number. Discussions with HK indicated that slides with sequential serial numbers were indeed sequentially manufactured. The bolts of these pistols are broached and then treated.

Lardizabal reported that fired cartridge casings from the two sequentially numbered slides had significantly corresponding breech face markings which were coming from a toolmark above the firing pin hole which appears to have been made after the finishing process. No other marks could be used to identify a casing to one of the two firearms. It was not stated why this was so, but HK pistols of this type do not leave very good quality markings. Casts of the breech faces also demonstrated good correspondence. This mark persisted after 250 test fires!

Cartridge casings fired from the other firearm with the lower serial number demonstrated no correspondence to the other two weapons. In addition, intercomparison of test fired bullets from each of the three firearms demonstrated good correspondence but comparison of bullets fired from different barrels demonstrated no apparent correspondence other than that which would be expected to occur at random. In summary, the author states that, "These exams validate identification of toolmarks. Changes in manufacturing and/or assembly techniques can present new challenges to the Firearm and Toolmark Examiner. The identification of breech face impressions on fired cartridge cases from pistols B and C serve as Subclass identification in that the toolmark on the breechfaces of the respective pistols is at least a second generation toolmark. Other marks should of course be found to facilitate identification."

Most recently, Thompson cited a case example which involved Lorcin 9-mm luger semi-automatic pistols (17). Thompson remarked that the Lorcin breech faces are stamped and painted with heavy black paint with no further finishing. This results in significant family resemblance with a significant possibility of a misidentification based on breech face markings alone. Thompson, like Lardizabal, suggest the use of other markings including extractor and chamber markings to facilitate such identifications.

Toolmarks

In 1942, Burd and Kirk published an often cited study which dealt with toolmarks (18). Up to that point in time, little had been published which specifically dealt with toolmarks. The main purpose of their paper was to relieve common misconceptions that toolmarks were not unique to a specific tool. They addressed four areas in their study. The first was to determine the effects that varying the method of tool application on a surface would have on the resultant toolmark. The second was to establish some criteria for identification. The third was to assess the similarity of toolmarks made by different tools which were similarly manufactured. Last, they hoped to attempt at least some classification of toolmarks that are encountered.

Throughout their study, they appear to be dependent upon a necessary percentage of lines that have to match in order for an identification to be affected. However, closer scrutiny of their language and testing would make it appear that this was simply a convenient language to use. Prior to this time, individuals associated a criterion for identification with a specific minimum number of lines that needed to correspond. Achieving such a number was simply not possible because, as Burd and Kirk pointed out, some known nonmatches may have a high number of corresponding lines simply because there was a high number of lines to begin with. They observed 20–25% matching lines in some known nonmatches during the course of the study.

As a result, they focused on proportion of matching lines. This appeared to be an attempt to use objective language for a subjective issue. They recognized that contour was a major factor in effecting an identification. At one point they state, ". . . it is the appearance of contour that is essential in determining whether a poor line match is adequate to establish identity." They go on to say, "When the latter factor matches [contour], as demonstrated by identity of distribution, width, depth, etc., of lines, it is actually not highly significant to know the exact number or proportion of matching lines." They appear to associate proportion of matching lines with contour when they report that, "The proportion of matching lines, on the other hand, will never be high unless the contour is very similar which in turn will not happen except when the same tool is used."

Overall, this appeared to be a well-done study. It is replete with statements that, if taken out of context, can be made to say something very different than what the authors had intended. It is necessary to read the paper as a whole and understand the time frame for which it was written. When evaluated in such a manner, Burd and Kirk's work remains as valuable today as it was in 1942.

Twenty-six years later, Burd participated in another toolmark study, this time with Gilmore (19). They discussed the individual and class characteristics of tools, specifically screwdrivers. In actuality, this paper dealt with what we would describe today as persistence of subclass characteristics and the potential confusion with individual characteristics. For their study, they randomly selected three screwdrivers from a distributor's sale bin. Each of the three were similar in all aspects. They report that these screwdrivers were apparently either pressed or stamped in a die or mold.

They examined the screwdriver tips as well as toolmarks made with various parts of the tips including the faces, edges, and corners. They observed some correspondence of what would now be termed subclass characteristics. The faces of these three tips were similar which might be expected from a stamping process that is not followed by additional finishing processes. In addition, a portion of the edges appeared to be sheared by the stamping process. These also showed subclass correspondence from tip to tip. When test impressions were made from these surfaces, the resultant marks were very similar. Excellent photographs illustrate this quite well.

However, when striated toolmarks were prepared using the corners of the tools, there were significant differences in the markings each tool produced. This is also documented through the use of photographs. The method by which the striated marks were made does appear to be the method utilized most often when these tools are used for illegal purposes.

They do emphasize the need for the examiner to interpret the identification potential of the suspected toolmark in light of the manufacturing process of the tool that made the mark. This emphasis is quite obvious when they report, "identification of a toolmark necessitates a detailed study of the specific tool in question and an evaluation of its surface structure." In their conclusion they indicate that, "In all cases he [the examiner] must make a careful examination of the tools involved." They never state specifically how they feel regarding the reliability of an identification attained between two or more different toolmarks without the same tool. However, based on their emphasis concerning the necessity of a detailed examination of the specific tool, it would seem readily apparent that such an identification would be questionable.

In 1975, Butcher and Pugh published a study on bolt cutters and the marks that they produce (20). Overall, their paper was a discussion of bolt cutter blade manufacture, known match comparisons and known nonmatch comparisons. Apparently following the lead of Burd and Kirk, they discussed the comparisons results in proportions of matching lines.

Ten blades that they acquired were manufactured together as a batch of ten so that they would be as alike as possible. These blades were profiled with the leading edges and cutting faces appropriately ground. They were not tested. Ten other blades were selected at random from a fully manufactured and tested assembly collection. Test marks for each of the blades were made in lead and consisted of the entire cutting surface of the blades, approximately 4 mm. They then performed a series of known match as well as nonmatch comparisons.

Of 880 known nonmatch comparisons of the first set of ten blades, only three demonstrated what could be termed significant correspondence of striations. These three had 22%, 23%, and 25% matching lines. This contrasted to the range of 87–92% matching lines observed in known match comparisons. Comparisons of the second set of ten blades produced similar results. Only two nonmatch comparisons produced significant correspondence, 27% and 29%. This contrasted to a 88–93% range for known match comparisons.

Three points relative to criteria for identification were addressed in this paper. The first was the need for assessing the quality of a toolmark. Butcher and Pugh used the terms definition and character. The definition was a measure of mark quality whereas character essentially referred to contour.

The second was their use of the terms "true match" and "false match." They defined a "true match" as a "high percentage (>50%) of matching lines." A "false match" was defined as a match in which "a proportion of the lines correspond but that proportion is less than one-half of the total, i.e., there is a low percentage (<50%) of matching lines." These definitions appear to be established on Burd and Kirk's work in 1942.

The third point deals with an often quoted figure of 2 mm. At no point in their study do they state that for the purposes of identification, a toolmark *must* be 2 mm wide. Their discussion of this point was quite explicit. Introducing their study, they stated that, "In our experience a mark 2 mm wide will normally contain sufficient lines to allow for an accurate assessment of whether test and suspect mark correspond." They concede that marks smaller than this may be viable when they conclude that, "In those cases where the only suspect mark available is narrower than that [2 mm] the evidential value that can be assigned to a high percentage match will depend on the number of lines in the mark and the definition of the pattern."

In the latter part of the same year, Reitz published a brief report on the individuality of drill bits (21). Reitz acquired both sequentially ground and nonsequentially ground twist drill bits to determine if the marks produced by them could be uniquely identified to the bit which made them. Many different companies were consulted and although no discussion of the manufacturing methods for the bits was discussed, such bits are ground. Reitz concluded that the marks produced by each drill bit were indeed unique and that in each instance, an unequivocal identification could be attained.

In 1976, Vandiver published a study concerning the individuality of screwdrivers (22). He acquired seven pairs of screwdrivers from seven different companies. Six of these companies also provided manufacturing methods used to make the screwdrivers with Stanley Tools' being the most comprehensive. The report was accompanied by extensive photographic documentation of the screwdriver tips, including both faces and sides.

The conclusions Vandiver made appear to have been based on an examination of the blades themselves. Vandiver concluded that toolmarks left at a scene could be identified to a specific tool and that there is a variation in marks on screwdriver tips that is to be expected from each different manufacturer. Taking this point further, he felt it might be possible to determine possible manufacture of a screwdriver based upon a toolmark or fragment left at the scene provided that the manufacturer database was large enough. He also felt that a corollary to other types of tools was not totally unjustified based on the work he performed.

In 1978, Watson prepared a report summarizing his experiences with two consecutively manufactured knives (23). These knives were used to make test cuts in soft plastic using the same relative location of each of the two knives. He observed "no carry-over" when marks from two different knives were compared as well as when marks from the two different sides of the same knife were compared. When marks made by the same knife and the same side were compared, they were "reproducible." The conclusions were very subjective in nature, i.e., "reproducible" versus "no carry-over." The report was supplemented by three photographs, two of which depict known matches and one depicting a known nonmatch.

In 1980, Cassidy published a report detailing his study and comparison of consecutively broached tongue and groove pliers (24). For his study, Cassidy obtained three sets of upper and lower jaws which were sequentially broached and treated to no further manufacturing processes which could have obliterated any subclass characteristics left by the broaching tool. Additionally, three upper jaws which had gone through the entire manufacturing process were obtained for examination.

Cassidy examined the actual teeth of the pliers as well as the test marks made by them. He observed no "family" resemblance. This can be interpreted today as no subclass characteristics were observed which could be mistaken as individual characteristics. The photographic documentation in this report was excellent.

In addition to the value of the study itself, the reader was also left with the important impression that logical thought and critical thinking process was indeed a process not to be ignored. Cassidy detailed the broaching process of the teeth. He also detailed the typically twisting motion with these pliers were generally used to force door knobs. Through this discussion he was able to point out that the tool used to broach the teeth moved in a direction perpendicular to the motion by which the teeth made the actual striated mark. With such a combination, even if subclass characteristics were present on the teeth, they would not be reproduced in the striated marks. Additionally, after broaching, the pliers are subjected to other manufacturing processes which by their very nature produce only individual characteristics.

In 1982, Tuira published a study which involved the individuality of two consecutively manufactured knives (25). This study differed from Watson's in the way in which the knife blades were tested. Watson used a cutting motion whereas Tuira studied the marks obtained in the stabbing motion of inflated automobile tires. Tuira provided no detail as to the manufacture of the knife blades. After comparing test marks, he was able to conclude that, ". . . a positive identification is possible without any danger of confusion arising because of consecutive manufacture of the knives."

Hornsby published a study in 1989 detailing the manufacturing process of MCC Bolt Cutters as well as the results of comparing the cutting edges of the three cutters (26). He detailed the steps of the manufacturing process as it related to the cutting surface and how the process is batched such that having two consecutively manufactured cutters is highly unlikely. Hornsby randomly selected three cutters from the same production run for testing. Comparison of test marks enabled him to conclude that, ". . . tests disclosed individual characteristics so different that there would be no possibility of misidentification."

In 1991, Warren published a study involving rotary glass cutters (27). He reported a grinding operation was involved in the manufacture of such cutters. After testing several cutters, he was able to conclude that the pattern each cutter produced was repeated for each complete rotation and that these patterns were unique to each cutter.

In 1992, Hall published a study involving the use of bolt cutters (28). The main objective of this study was to determine the persistence of toolmarks made by bolt cutters over the course of multiple cuts. Essentially, he wished to determine if the first cut made by a bolt cutter could be identified to subsequent cuts. He performed a series of 25 such cuts. Secondary to his prime objective, Hall also compared marks produced from three consecutively assembled bolt cutters. He detailed the batch process used to manufacture the cutters and determined that the cutters he obtained were more likely to be consecutively assembled rather than consecutively manufactured in the classical sense.

Test cuts in lead were made along the entire cutting surface of the bolt cutters prior to any other cuts being made. The cuts were compared in known match and known nonmatch comparisons. Upon completion of these comparisons, Hall was able to conclude, "The jaw-long lead cuts of each bolt cutter were compared to each other with no identification being made, i.e., no remarkable similarities or correspondence of striations was noted. Only test cuts from the same bolt cutter could be identified to each other."

In 1985, Kreiser performed a study dealing with the mold marks left on lead cast bullets and whether these could be considered to be unique to the mold in which the bullet was cast (29). Kreiser provided a brief description of the mold making process. He was able to acquire six different mold blocks from a run of 75. The six he acquired numbered 1, 2, 3, 4, 38, and 75 in the production sequence. For comparisons, Kreiser cast several lead alloy bullets from each mold.

Kreiser observed that toolmarks in the cannelures and on the noses showed "some consistency" throughout the entire run. Additionally, toolmarks reproduced on the ogive and bearing surface "changed more quickly but still showed some consistency throughout the run." While performing this work, Kreiser observed that the toolmarks from the molds did not reproduce as well on some bullets as they did on others. Several reasons for this were hypothesized, but the implications were readily apparent. If one could expect to find correspondence on well marked cast bullets, poorly marked bullets would pose much more of a problem.

Photographs of the nose area of a bullet cast in mold number 1 compared versus bullets cast in mold numbers 4, 38, and 75 showed significant correspondence of the toolmarks. Kreiser called these toolmarks class characteristics because of their persistence through several molds. Based on an evaluation of Kreiser's work, it would not be inappropriate to classify these as subclass characteristics.

Mathematical and Computer Models

In 1970, Brackett published a study in which he examined the use of various models to study "idealized" striated marks (30). Brackett's idealized striations were considered to be individual elements within a set of striae, representing only a position in two-dimensional space. Such idealized striations were devoid of width, contour, or other individualizing characteristics. The models considered were geometric models, number-based models, random number outcome models, and random number replica models.

Brackett developed a model of striated toolmarks using the random number table. The proposed model was tested and found to be quite reliable not only by Brackett, but in later works by Blackwell and Uchiyama (yet to be discussed). He developed an ideal distribution equation which showed the independence of striae, i.e., the presence of one striation is independent of its neighbors presence and positioning. Brackett demonstrated consecutiveness to be a very powerful tool but because of the tediousness of the models, it was "not of immediate application to forensic problems." His study did spawn computer models as will be seen later.

The first published discussion regarding automated firearms identification systems was authored by Blackwell and Framan in 1980 (31). They expressed concern over the identification criteria that would be used by the computerized systems and performed a study which included a literature search and a simulation study. Actual test firings were not performed. The search of the literature resulted in scant results as they indicated in their report, "A literature search was conducted in which it was learned that there is currently no universal factual basis for establishing identity of a firearm. Biasotti has conducted research which could prove very useful to future developments in firearm identification."

Their simulation study applied Brackett's formulas and models which they found reliable and with which they were in general agreement. Their simulation run produced a run of five consecutive lines, but with a total number of striations which was four times that observed by Biasotti. As indicated by several authors, including Biasotti and Brackett, it is only reasonable to expect higher run sequences based on the sheer increase in number of striations. Biasotti's work was valuable in that he studied practical line counts which many examiners could readily relate too.

In 1981, a study was published by Deinet in which he desired to calculate the probability of random occurrence of matches using actual striated toolmarks (32). The cutting edges of 20 shears were ground on a grinding wheel to produce random imperfections on the blades. Two lead impressions were made from each of the shears and examined microscopically. A 1.2-mm length of each pattern was photographed and scanned into a computer. Using interactive computer input, the images were cleaned and evaluated such that the only concern was line position.

Three different probability theory models were examined including a combinatorial model; a renewal theory model, and a binomial function fit. The author examined the model requirements and found that, "If the manufacturing process produces machining marks on the tools, admitting the possibility of a false line match being mistaken for a true one, the model requirements are not fulfilled. However, the numerical values computed with the aid of models permit an evaluation of the degree of similarity. For automation of pattern comparisons a preselection is possible, but any probability-related statements require additional studies and examinations."

He did perform examinations based on Brackett's run distribution model and provided such results. Using the cyclic shifting process, a total striae count of 9.911 by 10^6 was achieved! Run size versus the number of such runs that might be expected was graphically represented.

In 1988, Uchiyama published the first of many works discussing identification criteria (33). Citing, ". . . no definitive or objective explanations to support the conclusions of identity reached by the examiner; and . . . no clear explanation about what is meant by the word 'identified', 'likely', 'not identified', or 'no correspondence,' " Uchiyama sought to develop a criteria for identification for land impressions.

He developed a probability equation based on actual test fired bullets. In conjunction with this, he developed a significance level. The reason for this approach was because it had been demonstrated that the total number of matching striae and percentage of matching striae were both inadequate to the task of establishing identity. The significance level indicated a goodness of fit and essentially established a probability of an accidental or random match of striae.

When the concept of consecutiveness was factored into his analysis, Uchiyama discovered that it had the effect of significantly lowering the significance levels. He remarked, "Consecutively matching lines are indeed one of the principle characteristics indicating the identity of bullets fired from the same gun."

In 1992, Uchiyama published a study in which he provided an estimate of the maximum number of consecutively corresponding lines that might be expected given certain considerations (34). He determined the probabilities of percent match and maximum number of consecutively corresponding striae based on: striae density; a critical coincidence ratio (CCR—a quantitative representation of how well two lines match with regards to width, a perfect match being 1); and striae width.

As might have been expected when the width of all lines was equal, the percent of matching striae increased with density and increased with decreasing CCR. Further, the number of consecutive matching striae also increased with increases in density and with decreasing CCR. However, when the widths of the lines were varied, the number of consecutive matching striae decreased with increasing deviations in striation width. When the coefficient of variation for striae width was 0.9 and the CCR was 0.8 the maximum number of consecutively corresponding striations was expected to be between 3 and 4, numbers very similar to those obtained by Biasotti. When the CCR was lowered to 0.2 which represents a high level of tolerance in associating lines with differing widths, the maximum number of consecutive corresponding striations was between 6 and 7 depending on striae density.

Summary

There is serious concern in the forensic community regarding the implications of the *Daubert* decision for various forensic disciplines. It becomes greater when some individuals tend to lump all forensic science into one batch when some say, "Thoughtful, validity-focused scrutiny from the courts—something that the forensic identification sciences have not previously been subjected to—is likely to have the effect of impelling these fields to *become* scientific so that they can give the courts what the courts really expect from them, and which they themselves aspire to offer (35)." It is quite disconcerting when someone purports that forensic science has made little if any attempts to be scientific.

Thirty-four articles have been summarized which all have had as a common concern the basis upon which an identification in firearms and toolmarks is achieved. Not all have generated quantifiable numbers which those in the legal field inextricably link to scientific progress. However, as was discussed in the early part of this article, all of these appear to be based at least in part on the scientific method which tests hypotheses by experimenting and making observations. Just because some numbers are not generated does not make something less scientific. These 34 individual studies and reports can hardly be thought of as "little if any" attempts to be scientific.

Certainly though, part of the problem stems from the way this material is presented (or not presented) in courts of law. It is incumbent upon qualified examiners to know their field and know it well. Bad and ill-prepared examiners do not mean that the science is bad, it just means that they are bad and ill-prepared examiners. Attaching numbers to the science will not make these examiners any better. Even worse, it could be easier to mask their inherent flaws when they can hide behind numbers.

In part, this article was written to stimulate examiners to review their own basis for their criteria for identification. Much work has already been done in this field and it is not necessary to reinvent the proverbial wheel. However, to avoid this, it is necessary to be able to articulate one's criteria for identification and provide justification of it in a court of law. This article summarizes many articles which may be utilized in combination with arduous microscopic training in known match and known nonmatch comparisons to help establish one's criteria for identification.

References

1. Biasotti A, Murdock J. Criteria for identification or state of the art of firearm and toolmark identification. AFTE J 1984 Oct;16(4):16–34.
2. Churchman J. The reproduction of characteristics in signatures of Cooey rifles. RCMP Gaz 1949 May;11(5):133–40.
3. Biasotti A. A statistical study of the individual characteristics of fired bullets. J Forensic Sci 1959 Jan;4(1):34–50.
4. Lutz M. Consecutive revolver barrels. AFTE Newsletter 1970 Aug;24–8.
5. Skolrood R. Comparison of bullets fired from consecutively rifled Cooey .22 caliber barrels. Can Soc Forensic Sci J 1975;8(2):49–52.
6. Freeman R. Consecutively rifled polygon barrels. AFTE J 1978 Jun;10(2):40–2.
7. Murdock J. A general discussion of gun barrel individuality and an empirical assessment of the individuality of consecutively button rifled .22 caliber rifle barrels. AFTE J 1981 Jul;13(3):84–111.
8. Hall E. Bullet markings from consecutively rifled shilen DGA barrels. AFTE J 1983 Jan;15(1):33–47.
9. Matty W. A comparison of three individual barrels produced from one button rifled barrel blank. AFTE J 1985 Jul;17(3):64–69.
10. Brundage D. The identification of consecutively rifled gun barrels. AFTE Twenty-Fifth Seminar;1994 Jun 5–10; Indianapolis (IN).
11. Brown C, Bryant W. Consecutively rifled gun barrels present in most crime labs. AFTE J 1995 Jul;27(3):254–8.
12. Matty W, Johnson T. A comparison of manufacturing marks on Smith & Wesson firing pins. AFTE J 1984 Jul;16(3):51–6.
13. Matty W. Raven .25 automatic pistol breech face toolmarks. AFTE J 1984 Jul;16(3):57–60.
14. Uchiyama T. Similarity among breech face marks fired from guns with close serial numbers. AFTE J 1986 Jul;18(3):15–52.
15. Thompson E. Phoenix arms (Raven) breech face toolmarks. AFTE J 1994 Apr;26(2):134–5.
16. Lardizabal P. Cartridge case study of the Heckler and Koch USP. AFTE J 1995 Jan;27(1):49–51.
17. Thompson E. False breech face id's. AFTE J 1996 Apr;28(2):95–6.
18. Burd D, Kirk P. Toolmarks: Factors involved in their comparison and use as evidence. J Police Sci 1942;32(6):679–86.
19. Burd D, Gilmore A. Individual and class characteristics of tools. J Forensic Sci 1968 Jul;13(3):390–6.
20. Butcher S, Pugh D. A study of marks made by bolt cutters. J Forensic Sci Soc 1975 Apr;15(2):115–26.
21. Reitz J. An unusual toolmark identification case. AFTE J 1975 Dec;7(3):40–3.
22. Vandiver J. New screwdrivers production and identification. AFTE J 1976 Mar;8(1):29–52.
23. Watson D. The identification of toolmarks produced from consecutively manufactured knife blades in soft plastics. AFTE J 1978 Jul;10(3):43–5.
24. Cassidy F. Examination of toolmarks from sequentially manufactured tongue and groove pliers. J Forensic Sci 1980 Oct; 25(4):796–809.
25. Tuira Sgt. Tire stabbing with consecutively manufactured knives. AFTE J 1982 Jan;14(1):50–2.
26. Hornsby B. MCC Bolt Cutters. AFTE J 1989 Jul;21(3):508.
27. Warren G. Glass cutter impression identification. AFTE J 1991 Oct;23(4):925–7.
28. Hall J. Consecutive cuts by bolt cutters and their effect on identification. AFTE J 1992 Jul;24(3):260–72.
29. Kreiser J. Identification of cast bullets and their molds. AFTE J 1985 Jul;17(3):88–90.

30. Brackett J. A study of idealized striated marks and their comparison using models. J Forensic Sci Soc 1970;10(1):27–56.
31. Blackwell R, Framan E. Automated firearms identification system (AFIDS): Phase I. AFTE J 1980 Oct;12(4):11–37.
32. Deinet W. Studies of models of striated marks generated by random processes. J Forensic Sci 1981 Jan;26(1):35–50.
33. Uchiyama T. A criterion for land mark identification. AFTE J 1988 Jul;20(3):236–51.
34. Uchiyama T. The probability of corresponding striae in toolmarks. AFTE J 1992 Jul;24(3):273–90.
35. Saks M. Implications of the *Daubert* test for forensic identification science. Sheppard's expert and scientific evidence 1994 Winter;1(3):427–32.

Additional information and reprint requests:
Ronald G. Nichols
Oakland Police Department
Criminalistics Laboratory
455 Seventh St.—Rm 608
Oakland, CA 94607