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PAPER

CRIMINALISTICS

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Confocal Microscopy Analysis of Breech Face Marks on Fired Cartridge Cases from 10 Consecutively Manufactured Pistol Slides*

ABSTRACT: Recent publications from the National Academy of Sciences have called for additional foundational research in the field of firearm and toolmark analysis. We examined test fires from 10 pistol slides with consecutively manufactured breech faces. A total of nine test fires from each pistol slide, for a total of 90 test fired cartridge cases, were compared using confocal microscopy combined with three-dimensional cross-correlation analysis algorithms. A total of 8010 comparisons were performed (720 matches and 7290 nonmatches). The average score for matches was 0.82 with a standard deviation of 0.06. The average score for nonmatches was 0.20 with a standard deviation of 0.03. Additionally, subclass toolmarks were observed on the breech faces, but the presence of subclass was not detected in the correlation analysis. There was no overlap of scores between matching and nonmatching test fires. This provides objective data that support the AFTE (Association of Firearms and Tool Mark Examiners) theory of identification.

KEYWORDS: forensic science, firearm identification, confocal microscopy, consecutive manufacture, breech face, subclass marks, individual marks

Firearms and toolmark examiners have previously studied the microscopic marks produced by consecutively manufactured firearms and tools (1–3). This research has resulted in convincing the practitioners of firearms identification that the science of firearms identification is scientifically valid. The primary purpose of this work is to revisit the hypothesis that each firearm is capable of leaving unique marks, even when it is part of a set that is consecutively manufactured, in this case, by broaching and sand blasted operations. Consecutively manufactured firearms or tools are sequentially machined using the same machining tools. Therefore, consecutively manufactured tools are the most likely to have similar subclass (subclass marks are toolmarks incidental to manufacture and carry across more than one manufactured item. See Fig. 3 for an example), or even identical toolmarks, in comparison to firearms or tools manufactured with different cutting tools. While it is unlikely an examiner would encounter consecutively manufactured firearms or tools in a criminal case, by examining these extreme scenarios, examiners can be assured differentiating nearly identical patterns is possible. Specifically, when consecutively manufactured breech faces were examined, studies demonstrate that examiners could accurately differentiate between the samples (4–7).

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Two recent publications from the National Academy of Sciences have called for additional validation and foundational research within the field of firearms identification (8,9). Despite the previously described research and publications, the authors of National Academy of Sciences publications were unconvinced that Firearms and Toolmark Identification is on a solid scientific foundation.

To help address the criticisms of firearms and toolmark identification, additional scientific studies with objective data are needed. This is the reason we decided to use confocal microscopy because the data allow for more objective mathematical and statistical analysis. This article adds to a growing body of work that uses three-dimensional surface topography and algorithmically derived data to study and compare microscopic marks produced by firearms and tools (10–12).

Materials and Methods

Ruger Pistols

The authors decided to use Ruger P-series 9-mm Luger caliber pistols as the model for this study (Note: certain commercial equipment is identified in this article. Such identification does not imply recommendation or endorsement by National Institute of Standards and Technology [NIST], nor does it imply that the equipment are necessarily the best available for the purpose). As part of their manufacturing process, Ruger uses a gang broach to shape the breech face in the slide and therefore has the potential for producing subclass toolmarks (13,14). The Ruger Prescott factory (Prescott, AZ) provided us with ten 9-mm Luger caliber pistol slides. The breech faces of these slides were attested by the manufacturer to have been consecutively manufactured, and Ruger provided a certified letter attesting to this fact. In addition, we obtained one complete 9-mm Luger caliber P-95DC pistol (slide, frame, magazines, and barrel). The slide that accompanied this pistol was not part of the consecutive machining. It is important in firearm identification to understand which machining steps produce the microscopic toolmarks on each breech face (Fig. 1). The Ruger production manager informed us of the exact sequence of manufacturing steps for each pistol. The machining steps that have potential to leave toolmarks on the breech face are described as follows:

- The slide blank is first shaped on a Matsuura computer numerically controlled (CNC) machining center (Matsurra Machinery Corporation Sudbury, MA). CNC machining typically involves milling cuts, and thus milling marks could potentially appear on the breech face.
- The final breech face profile is cut using a gang or step broach. A broaching operation uses a multipoint or toothed tool to remove material with a single pass of the tool. The tool is passed in one direction past the work piece. As the tool passes the work piece, each tooth removes a small amount of material. This machining step will typically leave parallel, striated toolmarks. The toolmarks from step 1 above are effectively removed from the breech face area.
- The slide surfaces are de-burred both by die grinder and by hand. This process removes rough edges from the recently cut slide.
- The cartridge recess is milled. The cartridge recess is a small, fingernail shaped cut located on the left interior wall, just forward of the breech face. This feature helps the extractor hold a spent cartridge case in place when no magazine is present. With a magazine inserted, the next cartridge holds the spent case at the right attitude when it strikes the ejector. Without a magazine and cartridge recess, a spent case would slip downward and have a propensity to not eject properly.

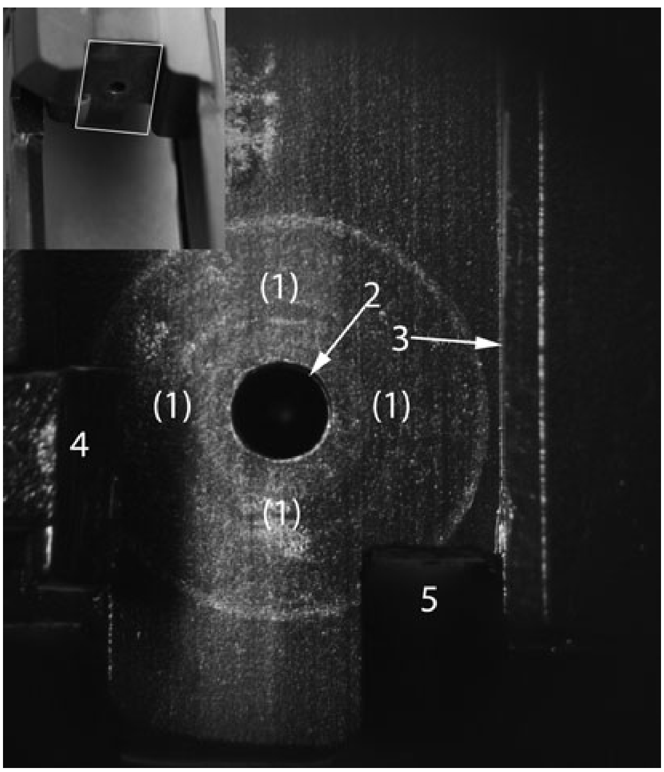

FIG. 1—*Inset shows location of breech face on pistol slide, highlighted portion is magnified view. 1-breech face. 2-firing pin aperture. 3-cartridge recess (on side, not visible). 4-extractor. 5-ejector cutaway.*

- The slide is polished and heat treated. Heat treating will harden the steel, making it strong enough to withstand the firing of ammunition.
- Slides are tumbled in a ceramic media to further remove rough edges.
- The slides are subjected to an automated sand blast and bead blasting process. The breech face is not masked during this process, and thus, the blasting media can strike the breech face in a random fashion. The primary purpose of this process is to blast the exterior for cosmetic reasons, and any marks on the breech face are not intentional. At this point, some of the other model P-series pistols have the breech face burnished to produce a smoother finish. The model we received was not subjected to this burnishing process because this particular model does not have problems feeding cartridges. Therefore, the burnishing is not necessary and is not done on currently produced P-95 model firearms.
- The firing pinhole is chamfered, leaving a slight tapered edge at the firing pin aperture.
- The slide is cleaned, blued, and inspected.
- Each slide is subjected to proof testing, followed by function test fires with at least 10 cartridges that are loaded to normal Sporting Arms and Ammunition Manufacturers' Institute pressure. Thus, a minimum of 11 cartridges were fired in each slide prior to leaving the factory (15).

Ammunition

Differences in ammunition can affect the quality of marks (12,16–18). Therefore, to focus this research to the similarities and differences between the breech faces, the authors decided to limit this study to one type of ammunition. We used the one extra pistol slide that was not part of the 10 that were consecutively machined to test four different brands of ammunition. We found all four marked well, but selected Winchester ammunition firing a 147 grain bullet because the marks were well defined and covered the entire primer surface. A total of nine test fires from each consecutively made breech face, for a total of 90 fired cartridge cases were collected. Additionally, five test fires with the same Winchester ammunition were saved from the nonconsecutively made breech face that was part of the complete pistol assembly.

New firearms will sometimes show a brief wear-in period where the microscopic marks can change over the first several test fires. We were aware of the phenomenon and monitored the confocal data for this trend. We observed no significant difference in this data between the first and last test fires.

Confocal Microscopy

Confocal microscopy allows for the acquisition of three-dimensional topography in a quick and nondestructive manner. Confocal microscopy incorporates pinhole optics to detect surface topography (Fig. 2). White light from a xenon bulb source enters through the objective of the microscope and illuminates the surface. The light reflects back into the objective and is directed onto a pinhole. Only the light reflected back from the current focal plane can focus through the pinhole and onto the detector. The microscope scans through a range of Z-slices or focal heights during the acquisition. At the end, all the slices are compiled into a three-dimensional topography map. The three-dimensional topography of the test fires were collected using a Nipkow disk confocal microscope located at the NIST. All topography measurements are performed in a temperature controlled laboratory of 20 ± 0.1°C. The same microscope is used to measure the NIST standard bullets and cartridge cases (19). Additionally, the Nipkow disk confocal microscope was used during feasibility assessment of a proposed national ballistics database (12). Owing to the dimensions of the breech face and the selected 10× magnification, one field of view (1.6 × 1.6 mm) was unable to capture the entire breech face impression. Instead, a 3 × 3 matrix of images was collected and mathematically stitched together. A total combined area of 4.3 × 4.3 mm was captured with an 80 pixel overlap between each field of view. The microscope scanned through 170 μm of vertical height at 0.20 μm per slice resulting in *c.* 850 slices.

Cross-Correlation Analysis

The procedures for data collection, processing, and cross-correlation analysis were developed during the 2007 feasibility assessment (12). The same techniques and processes described under "Data Processing for Topography Measurements" in that report were employed. An areal cross-correlation function was calculated for pairwise comparisons of the three-dimensional topography images in the same way as that described in the above study. The function is given by:

$$\mathrm{ACCF}(A,B,\tau_x,\tau_y) = \frac{\mathrm{ACCV}(A,B,\tau_x,\tau_y)}{Sq(A)Sq(B)} \quad (1)$$

where,

$$Sq = \left[\frac{1}{L_xL_y}\int_{-L_x/2}^{L_x/2}\int_{-L_y/2}^{L_y/2} Z^2(x,y)dxdy\right]^{\frac{1}{2}} \approx \left[\frac{1}{MN}\sum_{k=1}^{M}\sum_{j=1}^{N} Z^2(j,k)\right]^{\frac{1}{2}} \quad (2)$$

and,

$$\mathrm{ACCV}(A,B,\tau_x,\tau_y) = \left(\frac{1}{L_xL_y}\int_{-L_y/2}^{L_y/2}\int_{-L_x/2}^{L_x/2} Z_A(x,y)Z_B(x+\tau_x,y+\tau_y)dxdy\right) \quad (3)$$

L_x and L_y are the lengths of the topography in the *x* and *y* direction, respectively. Variable Z_A represents the reference topography matrix and variable Z_B represents the compared topography matrix. Variables τ_x and τ_y represent the shift distances in the *x* and *y* direction during registration process.

The Root Mean Square Roughness (*Rq*) (Eq. [2]) is a term used to describe how rough a surface is. The cross-covariance function (Eq. [3]) is a statistical function that quantifies the similarity of two sets of data. The Auto Cross Correlation Function (ACCF) is calculated by normalizing the cross-covariance function over the product of the *Rq* of both data sets as seen in Eq. (2).

Before the ACCF score is calculated, both the reference and compared data sets go through two types of filters. First the program finds the dropouts and outliers in the data set and a mask is created to exclude them from the later registration calculations. The outliers and dropouts are interpolated with respect to surrounding data. Then the data set goes through a truncated Gaussian filter (20) to remove the long-wavelength deviations and short-wavelength noise. The effective long and short cutoffs of these filters are *c.* 150 and 15 μm, respectively. Once the filters are completed, the registration and correlation between a pair of topography begins. In the registration process, the program shifts and rotates the compared data set with respect to the reference data set in *X*, *Y*, and θ to find the position where the ACCF score (Eq. [1]) reaches a maximum value. The ACCF score ranges from 0 to 1.00. A score of 1.00 (100%) would indicate a perfect point to point match between the two data sets.

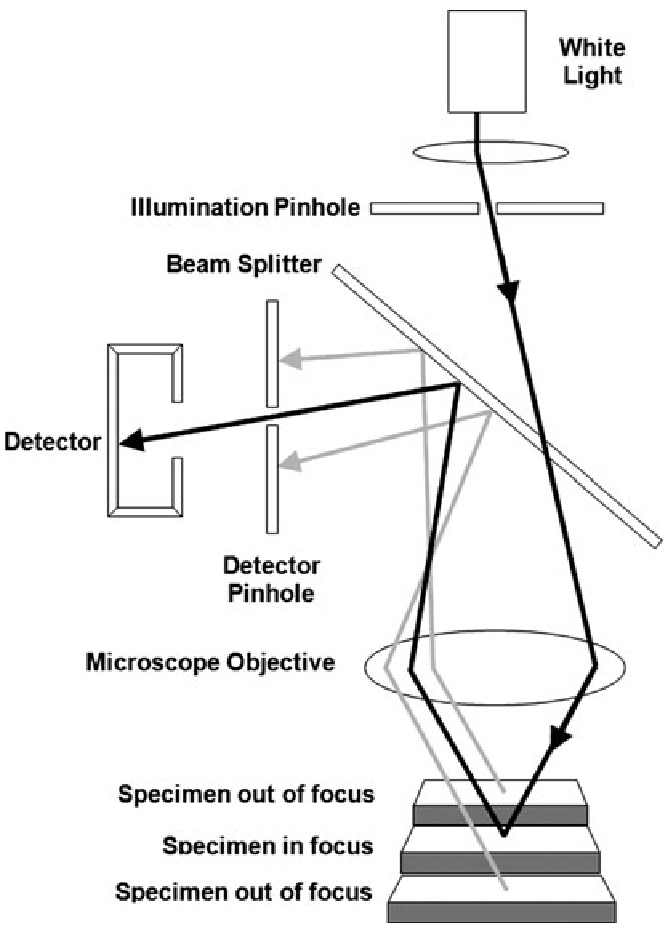

FIG. 2—*Diagram of confocal microscopy (20).*

Results

Traditional Microscopy Observations

First, each breech face was examined with a stereo microscope. The toolmarks were a mixture of parallel toolmarks and random roughness. The parallel toolmarks were produced by the broach machining step, and the random roughness was produced by the sand/bead blasting step. Prior to collecting test fires from each slide, Forensic Sil (silicone rubber; Loci Forensic Products, Nieuw-Vennep, the Netherlands) casts of each breech were collected and compared under a comparison microscope. Correspondence of the broaching toolmarks (parallel lines) was observed between all breech faces, including the first and 10th produced sample (see

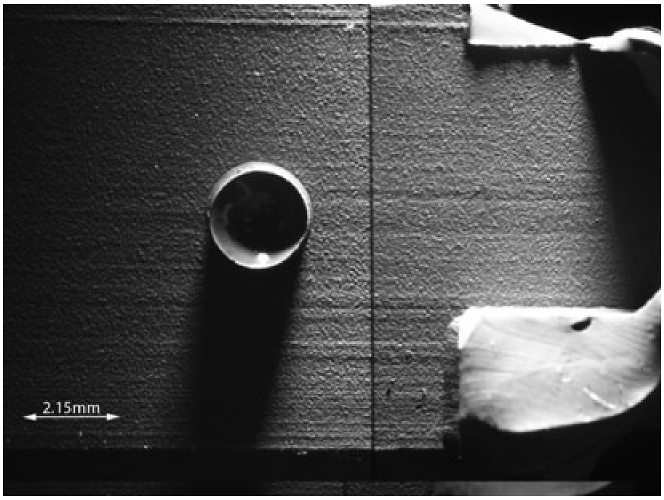

FIG. 3—*Comparison microscopy of Forensic Sil casts taken from the first and the 10th consecutively made breech face. The parallel lines, left by the gang broach machining process, carry across the breech faces. This shows that subclass characteristics are present. The circular object in the left field is from the firing pin aperture.*

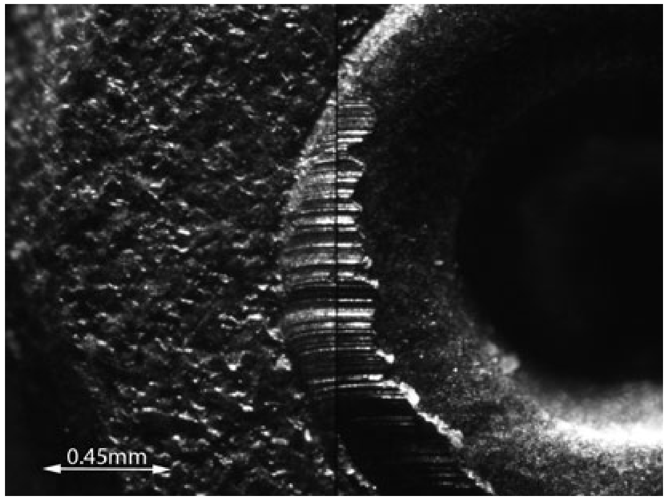

FIG. 5—*Comparison microscopy of primer shear toolmarks left on the primer flow-back portion of two test fires. Note the high amount of striated toolmark correspondence between the two. Unfortunately, the Nipkow disk confocal microscope could not reliably image this portion of the test fires*

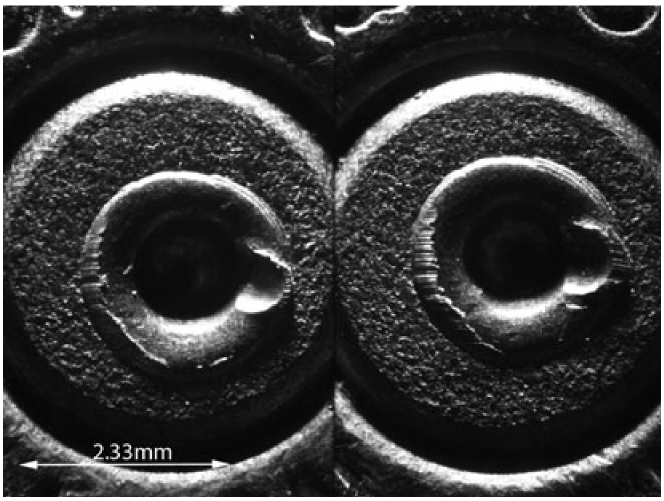

FIG. 4—*Comparison microscopy of two test fired cartridges marked by the same breech face. See Figs 5 and 6 for greater magnified views of the toolmarks present on these representative samples.*

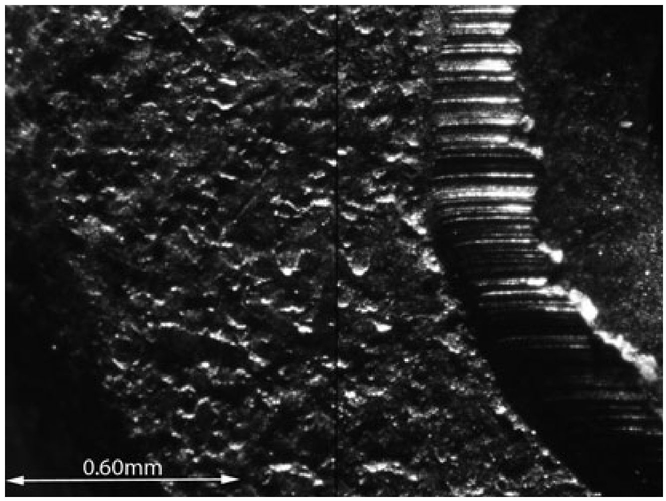

FIG. 6—*Comparison microscopy of breech face impressions on two test fires. These marks are caused by the sand/bead blasting process. The same features can be seen on both surfaces near the center dividing line.*

Fig. 3). In other words, subclass toolmarks were present on the consecutively made breech faces. However, many of these striated marks will not be viewed on a fired cartridge case because the cartridge case primer area (Fig. 4) is much smaller than the entire breech face surface.

The 90 test fires (nine from each of the 10 consecutive breech faces) were initially examined and compared under a comparison microscope. For providing identifications, the authors found firing pin aperture shear toolmarks easiest to compare under the comparison microscope (Fig. 5). However, owing to the relative steep angle of these marks in relation to the primer surface, these marks were not well imaged and resolved by the Nipkow disk confocal microscope. The authors also found reproducible marks left by the rough sand/bead blasted surface across most of the primer surface (Fig. 6). When comparing nonmatching test fires (test fires from different breech faces), any correspondence of the sand/bead blasting marks appeared coincidental in the comparison microscope and did not rise to the same level of correspondence as that observed between matching test fires. Finally, the parallel lines from the broaching process were present but these were difficult to observe because of the heavy influence of the sand/bead blasting marks.

To test whether the breech face and primer shear marks were sufficient for firearms identification, a blind test was prepared and provided to a firearms examiner. The test consisted of 11 unknowns (that consisted of the same test fires from this study): one from each consecutively made slide and one from the nonconsecutive slide. The examiner was also provided with two "test fires" from each of the 10 consecutive slides, but not from the nonconsecutive slide. The examiner correctly associated each unknown to the corresponding "parent" pistol and also eliminated the nonconsecutive slide sample.

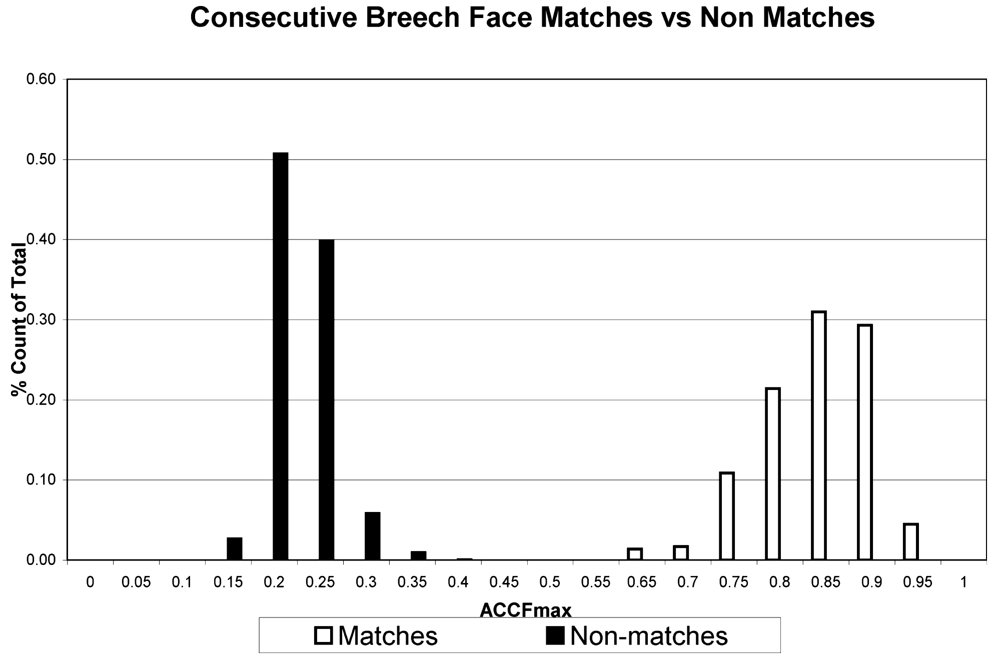

FIG. 7—*Plot of all 8010 cross-correlation comparisons between test fires from consecutively manufactured breech faces. No overlap of data was observed between matching (same breech face) and nonmatching (different breech face) comparisons.*

Confocal Microscopy Results

The confocal microscopy data from the 90 test fires were compared using the cross-correlation software. This involved a total of 8010 comparisons (720 matches and 7290 nonmatches). The maximum cross-correlation score was recorded for each comparison, and the distribution of scores is plotted in Fig. 7. At no point did a cross-correlation score from a nonmatch comparison overlap with a score from a match comparison. The scores between matching comparisons and nonmatching comparisons are well separated, as observed in Fig. 7. This is further demonstrated by viewing the means and standard deviations (Table 1).

To assess whether the subclass toolmarks (parallel lines) were having an influence on the correlation scores, an additional set of cross-correlation comparisons were made. Five test fires from the nonconsecutively made breech face were also imaged with the confocal microscope. This breech face was not made in sequence with the other 10 and therefore not likely to share subclass characteristics. Comparison of Forensic Sil casts confirmed this hypothesis (Fig. 8). If subclass resemblance across the consecutively made breech faces was influencing the cross-correlation scores, it would be reflected as higher nonmatch ACCF values. No significant difference in the mean ACCF value was observed when this analysis was performed as seen by comparing the second and third rows in Table 1. This indicates that the subclass toolmarks had no mathematically detectable influence in the cross-correlation scores.

TABLE 1—*Average and standard deviation for ACCFmax scores both in consecutive matching and nonmatching cases. Also nonconsecutive matching and nonmatching cases.*

Sample Population	Mean ACCFmax	Standard Deviation
Matching test fires from 10 consecutively made breech faces	0.82	0.06
Nonmatching test fires from 10 consecutively made breech faces	0.20	0.03
Nonmatching test fires from nonconsecutively made breech face vs. 10 consecutively made breech faces	0.23	0.04
Matching test fires from the nonconsecutively made breech face	0.83	0.06

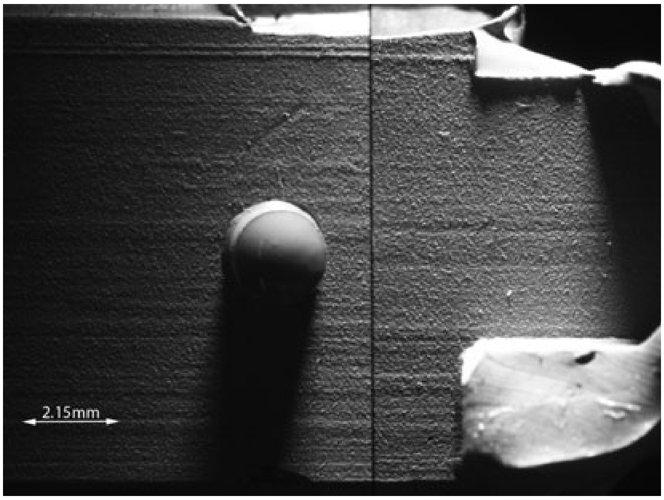

FIG. 8—*Comparison microscopy of Forensic Sil casts between a consecutively made breech face and the nonconsecutively made breech face. The parallel lines do not show the same degree of correspondence when compared to those observed in Fig. 3.*

Discussion

A review of the relevant scientific literature revealed that this research documents and reports on the first analysis of microscopic impression toolmarks from consecutively manufactured firearm surfaces using confocal microscopy and mathematical comparison by cross-correlation algorithms. The data strongly support the hypothesis that for the type of manufacturing processes studied, marks left by the breech face can be used both to distinguish between firearms and to associate fired evidence to a particular firearm. We would like to highlight that we did not observe a high cross-correlation value for nonmatching comparisons. At this time, supported by the selected weapon and ammunition, the research provides objective scientific support that even with the high degree of topographical similarity between consecutively manufactured surfaces, one can still correctly separate the surfaces based on their random surface features.

After reviewing the confocal and cross-correlation data, the authors were interested in how closely the cross-correlation data, especially with regard to the subclass toolmarks, mirrored our initial comparison microscopy observations. When viewed under the comparison microscope, the predominant microscopic marks were from the sand/bead blasting step. As the sand/bead blasting process produces surface features that are random in nature, no two surfaces produced by this process would be exactly alike. The cross-correlation data demonstrated no significant subclass influence, indicating the bead blasting toolmarks were the predominant topography evaluated by the cross-correlation algorithms. This result indicates that the cross-correlation techniques used in this study may be applicable for additional studies of other firearms and toolmark phenomena.

However, a significant amount of further research, testing, and validation needs to be conducted before confocal microscopy and cross-correlation analysis rises to the threshold of general acceptance in the firearms examiner community. Until that time, the techniques described in this article could prove to be useful in providing objective data to the scientific community to test further the foundations upon which the science of firearms and toolmark identification now rests.

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References

1. Bonfanti MS, de Kinder J. The influence of manufacturing processes on the identification of bullets and cartridge cases—a review of the literature. Sci Justice 1999;39(1):3–10.
2. Grzybowski R, Miller J, Moran B, Murdock J, Nichols R, Thompson R. Firearm/toolmark identification: passing the reliability test under federal and state evidentiary standards. AFTE Journal 2003;35(2):209–41.
3. Nichols R. The scientific foundations of firearms and tool mark identification—a response to recent challenges. *The CACNews 2006* 2006;2nd (Quarter):8–27.
4. Bunch SG, Murphy DP. A comprehensive validity study for the forensic examination of cartridge cases. AFTE Journal 2003;35(2):201–3.
5. Coody AC. Consecutively manufactured ruger P-89 slides. AFTE Journal 2003;35(2):157–60.
6. Lopez L, Grew S. Consecutively machined ruger bolt faces. AFTE Journal 2000;32(1):19–24.
7. Matty W. Raven 25 automatic pistol breech face tool marks. AFTE Journal 1984;16(3):57–60.
8. National Research Council. Ballistic imaging. Washington, DC: National Academies Press, 2008.
9. National Research Council. Strengthening forensic science in the United States: a path forward. Washington, DC: National Academies Press, 2009.
10. Bachrach B, Jain A, Jung S, Koons RD. A statistical validation of the individuality and repeatability of striated tool marks: screwdrivers and tongue and groove pliers. J Forensic Sci 2010;55(2):348–57.
11. Chu W, Song J, Vorburger T, Yen J, Ballou S, Bachrach B. Pilot study of automated bullet signature identification based on topography measurements and correlations. J Forensic Sci 2010;55(2):341–7.
12. Vorburger TV, Yen JH, Bachrach B, Renegar TB, Filliben JJ, Ma L, et al. Surface topography analysis for a feasibility assessment of a national ballistics imaging database. A report prepared for the National Academies Committee to assess the feasibility, accuracy, and technical capability of a National Ballistics Database. NISTIR 7362 2007;1–171.
13. Biasotti AA. Rifling methods—a review and assessment of the individual characteristics produced. AFTE Journal 1981;13(3):34–61.
14. Miller J, Beach G. Toolmarks: examining the possibility of subclass characteristics. AFTE Journal 2005;37(4):296–306.
15. Sporting Arms and Ammunition Manufacturers' Institute, http://www.saami.org/ (accessed January 5, 2011).
16. Davis J. Primer cup properties and how they affect identification. AFTE Journal 2010;42(1):3–22.
17. De Kinder J, Tulleners F, Thiebaut H. Reference ballistic imaging database performance. Forensic Sci Int 2004;140(2-3):207–15.
18. Tulleners F. Technical evaluation: feasibility of a ballistics imaging database for all new handgun sales. *CALDOJ Publication*, 2001;October 5.
19. Song J, Vorburger T, Renegar T, Rhee H, Zheng A, Ma L, et al. Correlation of topography measurements of NIST SRM 2460 standard bullets by four techniques. Meas Sci Technol 2006;17:500–3.
20. The American Society of Mechanical Engineers (ASME). B46.1-2009-Surface texture (surface roughness, waviness, and lay). New York, NY: ASME, 2010.

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