Fordham Urban Law Journal

Volume 38
Number 2 *The Challenge of Urban Policing*

Article 2

2010

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ABSTRACT

Analysis of ballistics evidence (spent cartridge casings and bullets) has been a staple of forensic criminal investigation for almost a century. Computer-assisted databases of images of ballistics evidence have been used since the mid-1980s to help search for potential matches between pieces of evidence. In this article, we draw on the 2008 National Research Council Report[1] *Ballistic Imaging* to assess the state of ballistic imaging technology. In particular, we discuss the feasibility of creating a national reference ballistic imaging database (RBID) from test-fires of all newly manufactured or imported firearms. A national RBID might aid in using crime scene ballistic evidence to generate investigative leads to a crime gun's point of sale. We conclude that a national RBID is not feasible at this time, primarily because existing imaging methodologies have insufficient discriminatory power. We also examine the emerging technology of microstamping for forensic identification purposes: etching a known identifier on firearm or ammunition parts so that they can be directly read and recovered from crime scene evidence. Microstamping could provide a stronger basis for identification based on ballistic evidence than the status quo, but sub-

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1. We acknowledge the work of the National Research Council's Committee to Assess the Feasibility, Accuracy and Technical Capability of a National Ballistics Database. Committee members included: John Rolph *(Chair)*, Eugene Meieran *(Vice Chair)*, Alfred Blumstein, Alicia Carriquiry, Scott Chumbley, Philip Cook, Marc De Graef, David Donoho, William Eddy, George (Rusty) Gray, Eric Grimson, Daniel Huttenlocher, Michael Meyer, Vijayan Nair, Angelo Ninivaggi, David Pisenti, Daryl Pregibon, Herman Reininga, James (Chips) Stewart, Michael Stonebraker, Harry Wechsler, and Julia Weertman. The Committee's work was staffed by Carol Petrie, Daniel Cork, Gary Fischman, Michael Siri, Anthony Braga, and Lawden Yates. The Article also reports results from experiments conducted by the National Institute of Standards and Technology (NIST). Susan Ballou, Theodore Vorburger, Benjamin Bachrach, James Filliben, Dewey Foreman, John Libert, Brian Renegar, Mike Riley, John Song, James Yen, and Alan Zhang all participated in conducting and/or reporting on the NIST experiments.

stantial further research is needed to thoroughly assess its practical viability.

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INTRODUCTION

For much of the twentieth century, the forensic science of firearms identification was an intensively individualized activity. A firearms examiner inspected ballistics evidence (spent cartridge cases and bullets) under a comparison microscope, formed a mental pattern of identifying marks and features, and tried to match that pattern against other exhibits. Establishing connections between different cases depended on the memory recall of the firearms examiner or being able to recognize features from photographs in open case files or postings on bulletin boards.[2] Hence, searching through large amounts of ballistic evidence and verifying a match was a labor-intensive and time-consuming task.

Circumstances started to change rapidly in the late 1980s and 1990s as advances in compiling and searching computerized image databases were applied to forensic evidence analysis. The advent of the Federal Bureau of Investigation DRUGFIRE system (for cartridge cases) and the Bureau of Alcohol, Tobacco, Firearms, and Explosives (ATF)-funded BULLET-PROOF system (for bullets) made the first significant breakthroughs, permitting individual law enforcement agencies to begin searching new ballistics evidence against large volumes of already-captured images and suggesting possible "hits."[3] The late-1990s formation of the National Integrated Ballistic Information Network (NIBIN), under ATF, broke down the previously formidable geographic barrier by linking the image databases across multiple agencies and permitting searches within regions of the country.[4]

These advances in ballistic imaging technology allow images of bullets or casings to be cataloged, scored, and ranked. A firearms examiner can compare highly-ranked pairs of images on the screen, much as a radiologist might read a digital mammogram. If the matches are promising, the actual physical evidence can be retrieved for direct examination by a firearms examiner for confirmation.[5] The emergence of ballistic imaging also led to the notion of "cold hits"—database searches that could suggest linkages and connections between multiple crimes, without prior knowledge about such linkages—and fueled speculation as to exactly how far the technology could go.[6]

A particularly tantalizing prospect that gained some currency was the creation of a national reference ballistic image database (RBID) that would

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2. *See* NAT'L RES. COUNCIL, BALLISTIC IMAGING 86, 91 (Daniel L. Cork et al. eds., 2008) [hereinafter NAT'L RES. COUNCIL]; *see also* R.K. Maruoka, *Turning Unknowns Into Knowns: Linking Cartridge Cases to the Firearms and Suspects to Crime Scenes*, 26 AFTE J. 214 (1994).

3. *See* NAT'L RES. COUNCIL, *supra* note 2, at 93, 134-37.

4. *Id. supra* note 2, at 139-42; *see also* ATTORNEY GEN. BILL LOCKYER, CAL. DEP'T OF JUST., FEASIBILITY OF A CALIFORNIA BALLISTICS IDENTIFICATION SYSTEM: ASSEMBLY BILL 1717 (HERTZBERG) (STATS. 2000, CH. 271)—REPORT TO THE LEGISLATURE (2003); R.M. THOMPSON ET AL., BALLISTIC IMAGING AND COMPARISON OF CRIME GUN EVIDENCE BY THE BUREAU OF ALCOHOL, TOBACCO, AND FIREARMS 10-11 (2002).

5. NAT'L RES. COUNCIL, *supra* note 2, at 26-27.

6. For a discussion of the benefits of such "cold hits," see Anthony A. Braga & Glenn L. Pierce, *Linking Crime Guns: The Impact of Ballistics Imaging Technology on the Productivity of the Boston Police Department's Ballistics Unit*, 46 J. FORENSIC SCI. 701 (2004).

include images from test fires of all newly manufactured or imported firearms in the United States.[7] At a conceptual level, such a national RBID had the promise of early investigative leads: a cartridge casing recovered from a new crime scene could be entered and searched against the national RBID, generating an investigative lead to at least the initial point of sale of the gun used to fire the round, all without having to actually recover and obtain the gun.

There are several existing ballistic image database resources, but the hypothesized national RBID differed from them in several ways. The NIBIN system and database is not a *reference* database as it is legally restricted to include only exhibits from firearms used in crime or in law enforcement custody. Other existing RBIDs in the United States are not *national* in scope; the states of Maryland and New York instituted RBIDs, but those only covered firearms manufactured or sold within those states.[8]

In 2004, the National Institute of Justice (NIJ) requested the National Academies to convene a panel to "Assess the Feasibility, Accuracy, and Technical Capability of a National Ballistics Database" and study the issues surrounding the implementation of a national RBID. The findings were published in the Report *Ballistic Imaging*,[9] which predates *Strengthening Forensic Science in the United States: A Path Forward*.[10] The panel, on which the authors of the current Article served in different capacities, included experts from a wide range of scientific disciplines bearing on the application of imaging techniques and computerized search to assist firearms identification.[11] The disciplines covered include statistics, mechanical engineering, materials science and metallurgy, computer science, and manufacturing design. The panel's deliberations focused on the assessment of three basic policy options:

- Maintain the existing NIBIN system as-is, with its restriction to crime scene evidence;
- Enhance the NIBIN system in operational or technical ways to facilitate better matching of evidence images; or

7. NAT'L RES. COUNCIL, *supra* note 2, at 11.

8. *See, e.g.*, Responsible Gun Safety Act of 2000, S.B. 211, 2000 Reg. Sess. (Md.); MD. CODE. ANN., PUB. SAFETY § 5-131; N.Y. GEN. BUS. LAW § 396-ff (McKinney 2000); N.Y. COMP. CODES R. & REGS. tit. 9, § 493.1 (2000).

9. NAT'L RES. COUNCIL, *supra* note 2.

10. NAT'L RES. COUNCIL, NAT'L ACADEMY OF SCI., STRENGTHENING FORENSIC SCIENCE IN THE UNITED STATES: A PATH FORWARD (2009).

11. NAT'L RES. COUNCIL, *supra* note 2, at 312-22.

- Develop a national RBID including images from test fires of all newly manufactured or imported firearms.[12]

One major technical enhancement identified early in the study process was using three-dimensional surface measurements as "images" of ballistics evidence (and their associated toolmarks) instead of two-dimensional photography. To that end, the panel supervised a program of experimental work by the National Institute of Standards and Technology (NIST), funded under a separate NIJ grant.[13]

The panel also chose to investigate the emerging technology of microstamping: etching microscopic identifiers onto ammunition components or firearm parts so as to impose known markings onto ballistics evidence. This approach could also provide early investigative leads without requiring recovery of the crime gun using an alternative technology.[14]

This Article summarizes some of the policy themes in *Ballistic Imaging*, as an argument for the kinds of research on conceptual foundations in forensic science envisioned in *Strengthening Forensic Science*. We discuss the limitations and potential of technology as they apply to a particular forensic science application. In terms of the construction of a national RBID and the implementation of firearms microstamping, the panel concluded that both concepts were premature and needed more and substantial research.[15]

In Part I, we outline some basic issues in firearms identification, including the types of toolmarks and the problem of uniqueness. Part II describes the existing ballistic imaging hardware and software platform reviewed by the panel, the Integrated Ballistics Identification System (IBIS) and the means by which it compares and scores potential matches. Part III summarizes the original experimentation results and extant performance studies that contributed to the panel's central finding that a national RBID is inadvisable at this time. Part IV covers the state of the alternative technology of microstamping at the time of the panel's study, and we conclude with some general themes. Before we proceed further, some caveats are in order:

- An assessment of the admissibility of forensic firearms evidence in legal proceedings was not part of our charge and was beyond the expertise of our panel. This is clearly an important topic that is covered in other articles in this issue.

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12. *See id.* at 14, 16-17.
13. *See id.* at 17-18.
14. *See id.* at 257.
15. *See id.* at 4-5, 7.

- The current use of ballistic image databases requires comparison of the physical exhibits by a firearms examiner to certify a "hit" or match—presumably to ensure that someone can testify to the "hit" in legal proceedings.[16] Accordingly, we did not consider the issue of whether human firearms examiners might be replaced by a mechanical routine.
- Our study was "neither a verdict on the uniqueness of firearms-related toolmarks generally nor an assessment of the validity of firearms identification as a discipline."[17] Rather, we were asked to study "the uniqueness of ballistic images"—the uniqueness and reproducibility of the toolmarks on ballistics evidence as they are recorded or measured by various technologies (e.g., photography or surface measurement).[18]

I. FIREARMS IDENTIFICATION

Toolmarks are created when a hard object (generally, a tool) impacts a relatively softer object. In the case of modern firearms and ammunition, those marks are generated in the incredibly quick and inherently violent steps of the firing process. The firing pin jabs into the metal at the base of the ammunition cartridge—the soft brass of the circular primer cup in common centerfire ammunition or the cartridge brass of the outer rim of the cartridge in rimfire ammunition—causing a chemical primer mixture to ignite. In turn, this ignition causes the propellant or powder to burn, resulting in a rapid and intense buildup of gas pressure that slams the cartridge walls against the internal surfaces of the firearm (particularly the breech face against which the base of the cartridge is impressed and from which the firing pin protrudes). The gas pressure also unseats the bullet from the cartridge and propels it outward through the barrel of the gun, the bullet scraping against and gripping the "rifling" grooves that are typically carved in gun barrels to impart a spin (and added stability in flight) to the bullet. Additional marks are created at the extractor or ejector mechanism, cycling a spent cartridge from the chamber and allowing a new cartridge to enter.

There are several levels of hierarchy associated with the attributes of ballistics evidence exhibits. High-level *class* characteristics include gun caliber, shape of firing pin, number of lands and grooves, etc. These can be used to quickly screen out exhibits that could not have been fired from the same gun. At the other end, there are *individual* characteristics associated

16. *See id.* at 20.
17. *Id.* at 18.
18. *Id.*

with a gun, such as the fine striations on a bullet's surface or peculiar microscopic textures in the firing pin impression. There are also intermediate characteristics such as marks that arise from specific manufacturing techniques or flaws. These induce similar patterns on ballistics evidence even though they originated from different sources.

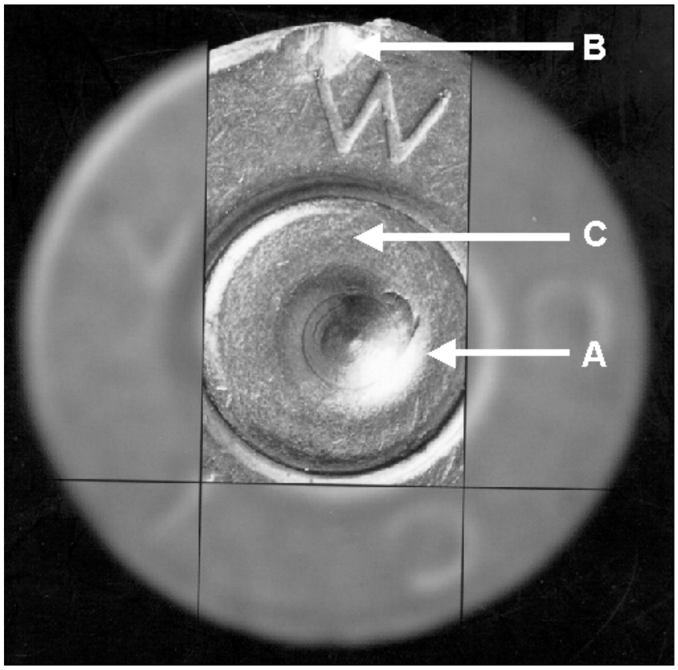
A. Toolmarks on Cartridge Casings

Figure 1 shows some examples of impressions that are left on cartridge casings. "Breech face impressions" are created when the gas pressure from firing a gun forces the base of the cartridge—particularly the relatively soft primer cap—against the hardened breech face. This may result in the surface area of the cartridge head picking up negative impressions of any linear striations or other features left on the breech face when it was filed and machined. Some of these marks may register on the relatively hard cartridge brass that forms the outer ring of the cartridge case base but those marks can be obscured by the head stamp that typically identifies the manufacturer of the ammunition; the markings left on the donut-shaped primer cup area, less the "pit" of the firing pin impression, comprise the breech face impression. Features in the breech face impression will depend on the specific filing or polishing steps used by the manufacturer. Straight filing creates linear features; other breech face impressions may feature cross-hatching or circular patterns.

The "firing pin impression" on the surface of the primer can provide information on the general class of the firearm that discharged a casing. The shape of the "pit" marking the firing pin's strike indicates the shape of the firing pin in the firearm (e.g., round, elliptical, rectangular). The bottom and walls of the pit of firing pin impression will also bear the marks created by filing or smoothing the tip of the firing pin.

"Ejector marks" can vary from tiny divots to more substantial indents on the cartridge head near the rim. The ejector arms in automatic or semiautomatic firearms vary in shape (e.g., rectangular, round, triangular) and size; the footprint of the ejector determines the size and shape of the mark left by the ejector on the rim of the spent casing.

Figure 1. Basic toolmarks on a centerfire cartridge: (A) firing pin impression, (B) ejector mark, and (C) breech face impression.[19]



B. Toolmarks on Bullets

Hatcher's text[20] on firearms identification refers to "the fine ridges and grooves on the surface of the bullet, parallel to the rifling marks," as "the most important individual characteristics which are used" in the field.[21] These marks, also known as striations, are caused when the bullet passes over the surface irregularities and rough spots that arise during the machining operations of reaming the bore and rifling the grooves. The pattern of land and groove engraved areas on recovered bullets can be used to determine basic information about the rifling characteristics of the gun that fired them. The number of lands and the direction of twist are important class characteristics. Bullets (and corresponding rifling characteristics) are

19. Original photograph by Forensic Technology Inc., reproduced from Vorburger et al. *See* T.V. VORBURGER ET AL., NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY 7362, SURFACE TOPOGRAPHY ANALYSIS FOR A FEASIBILITY ASSESSMENT OF A NATIONAL BALLISTICS IMAGING DATABASE 32 (2007).

20. JULIAN S. HATCHER, TEXTBOOK OF FIREARMS INVESTIGATION, IDENTIFICATION AND EVIDENCE 255 (1935).

21. *Id.*

commonly labeled by these two pieces of information—e.g., 5R for five lands and a right-hand twist. A recovered bullet can also be measured to suggest the caliber of the ammunition and weapon. However, this is not always possible due to the condition of some bullets recovered from crime scenes (and victims).

C. Uniqueness and Identification Issues

The development of an objective, statistical basis for firearms identification is challenging due to the multiple sources of randomness present when a gun is fired. Shots from even the same gun are not fired under the same exact conditions. Ammunition, wear and cleanliness of firearms parts, burning of propellant particles and the resulting gas pressure, etc., can vary across firings. Therefore, an examiner's assessment of the toolmarks and the decision on a match comes down to a subjective determination based on intuition and experience. The Association of Firearm and Tool Mark Examiners' (AFTE) "Theory of Identification"[22] specifies that "agreement is significant" between two toolmarks if the examiner is able to make two cognitive and inherently subjective conclusions: that "[the agreement] exceeds the best agreement demonstrated between toolmarks known to have been produced by different tools and is consistent with the agreement demonstrated by toolmarks known to have been produced by the same tool."[23] The AFTE Theory of Identification goes on to note that, "currently, the interpretation of individualization/identification is subjective in nature, founded on scientific principles and based on the examiner's training and experience."[24]

While we did not take any position on the fundamental assumptions of toolmark uniqueness and reproducibility that underlie firearms identification, we did make the following points:

- "Additional general research on the uniqueness and reproducibility of firearms-related toolmarks would have to be done if the basic premises of firearms identification are to be put on a more solid footing."[25]

22. Ass'n of Firearm and Tool Mark Examiners Criteria for Identification Comm., *Theory of Identification, Range of Striae Comparison Reports and Modified Glossary Definitions*, 24 AFTE J. 336 (1992) [hereinafter *Theory of Identification*]; *see also* Richard Grzybowski et al., *Firearm/Toolmark Identification: Passing the Reliability Test Under Federal and State Evidentiary Standards*, 35 AFTE J. 209 (2003).

23. *Theory of Identification*, *supra* note 22, at 337.

24. *Id.*

25. NAT'L RES. COUNCIL, *supra* note 2, at 89.

- "Conclusions drawn in firearms identification should not be made to imply the presence of a firm statistical basis when none has been demonstrated."[26]

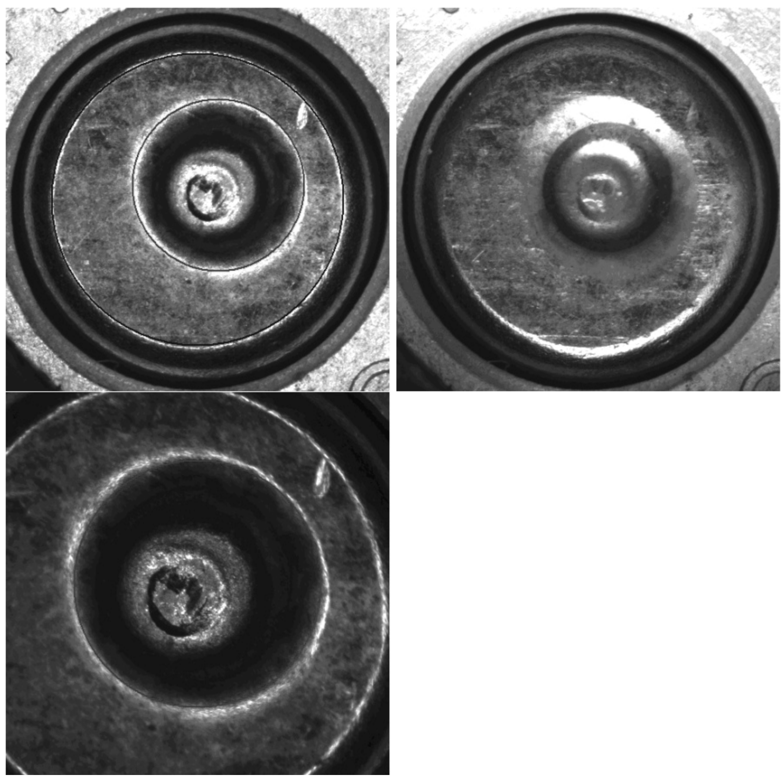
From the viewpoint of evaluating ballistic imaging techniques, however, one need not reach a conclusion on the uniqueness of firearm-generated toolmarks. As we describe in Part II, the results of queries to a ballistic image database are simply possible solutions to a statistical discrimination problem. Consequently, image database routines need only group like images alike *and* clearly distinguish like images from unlike images to be effective. The underlying reason as to *why* two images are considered like or unlike is not directly relevant when we are assessing the performance of image databases, although that question is of prime practical importance for evaluating forensic science.

26. *Id.*

II. COMPUTER IMAGES AND ASSESSMENT OF DATABASES

A. Two-Dimensional Technology

Figure 2. IBIS Breech Face Images. (a) Breech face image using the standard ring, center light [upper-left image]; (b) breech face image using the side light [upper-right image]; and (c) firing pin image using the standard ring, center light, acquired from the same cartridge casing [lower-left image]. The circular region-of-interest delimiters are indicated on images (a) and (c). The area between the outer circle and inner circle (a) defines the breech face impression, and the area inside the single circle (c) defines the firing pin impression.[27]



The two-dimensional (2-D) optical imaging technique inherent in the IBIS platform, developed and marketed by Forensic Technology, Inc. (FTI), emulates the performance of the original, standard comparison mi-

27. Reproduced from *Ballistic Imaging*. *See id.* at 99.

croscope in many respects.[28] More recently, FTI has made IBIS TRAX-3, a three-dimensional (3-D) imaging platform, the centerpiece of its operation, to the extent of marketing the 2-D models as a "heritage" system.[29] This section provides an overview of FTI's 2-D IBIS technology, on which *Ballistic Imaging* focused heavily because the 2-D system was what was deployed to participating law enforcement agencies in the NIBIN network.

Two-dimensional technology captures a photographic image of the physical object based on the projection of light reflected off of the three-dimensional object.[30] The basic equipment consists of a Remote Data Acquisition System, which includes a microscope with two built-in cameras (one for bullets and another for cartridge cases).[31] The IBIS technology allows the operators to set regions of interest on an image and then acquire the image using appropriate lighting. The fidelity of the 2-D optical images can be affected by several factors such as lighting conditions, reflection, color, optical properties of the surface, etc.[32]

Figure 2 shows two-dimensional images of breech-face impressions of a cartridge. Two circles define the region of interest for breech face impression: the outer circle is set to the edge of the primer surface of the stamp and the inner circle marks the firing pin impact region. For firing pin impressions from center fire guns, the region of interest is defined by a single circle (right panel of Figure 2). For firing pin and ejector mark impressions from a rimfire gun (where the firing pin strikes the head stamp area on the rim of the cartridge), the region of interest is freeform. The operators use the mouse to draw an outline around the mark to define the region.[33]

The acquisition of bullet images is more complicated and time-consuming. We focus on cartridge cases almost exclusively in this paper because the time and difficulty involved in collecting test-fired bullets and imaging them preclude their use in an RBID.

28. *See id.* at 93.

29. *See id.* at 94.

30. *See id.* at 93-101 (describing the IBIS equipment, data acquisition, and how operators use it).

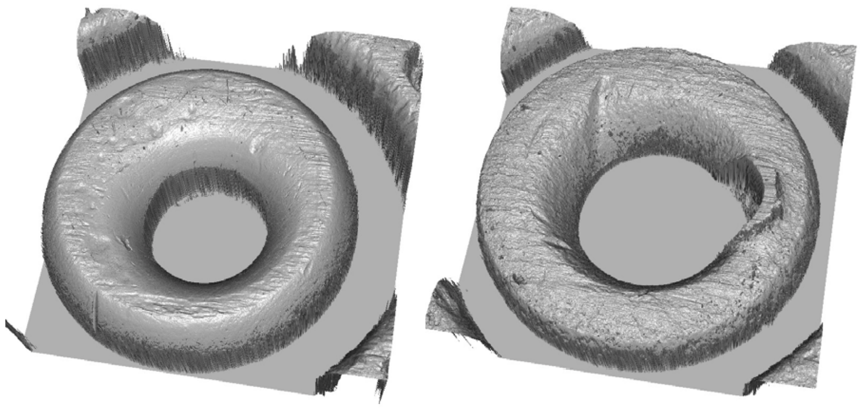
31. *See id.*

32. *See id.*

33. *See id.* at 97-100 (describing how operators specify the region of interest on a cartridge case using IBIS equipment).

B. Three-Dimensional Technology

Figure 3. Three-dimensional breech face images, firings from same SIG Sauer gun but two different ammunition brands.[34]



It is well recognized that using flat, two-dimensional representations of three-dimensional features have serious limitations. As advances have continued in the field of surface metrology, developments in three-dimensional measurement of ballistics evidence have begun to emerge. FTI was in the process of developing initial versions of 3-D systems during the late stages of our panel's work; the panel's work with NIST used experimental versions of topographic measurements to obtain 3-D data using a platform similar to the ones believed to be under development by FTI.[35] Figure 3 shows an illustrative rendering of two breech face impressions based on 3-D measurements collected by the NIST-developed platform.

Three-dimensional surface measurement techniques include both contact and noncontact methodologies.[36] For ballistics evidence analyses, most contact probes—for instance, tracing a surface using a stylus—do not have the level of resolution necessary to build a sufficiently detailed three-dimensional reconstruction of very fine, microscopic textures like those on

34. Reproduced from Vorburger et al. *See* VORBURGER ET AL., *supra* note 19, at 34 fig. 4-4.

35. *See* NAT'L RES. COUNCIL, *supra* note 2, at 199-200 (describing the NIST and the FTI 3-D systems and the panel's use of them).

36. *See id.* at 190-91 (summarizing both approaches).

bullet or cartridge case evidence.[37] A more fundamental difficulty is the potential for the evidence bullet or casing to be scratched or otherwise damaged by the contact.[38] Noncontact methodologies have emerged that have sufficiently high resolution. These methodologies include confocal microscopy, interferometry, and laser scanners.[39]

C. Signature Analysis

The captured image is used to generate "big" and "small" signatures of the cartridge casing or bullet. Big signatures contain a high level of detail and take up a great deal of memory space. Smaller signatures are less detailed but more efficient to use.[40] The exact techniques for extracting information from the IBIS signatures and comparing them with others are considered proprietary information by FTI. Our descriptions on scoring and comparison are derived from published articles and other public documents.

D. Scoring and Ranking

The next task is to compare the signature from a reference exhibit with hundreds or thousands of other signatures in a database to assess their similarity. FTI refers to this process as "correlation."[41] This is quite different from the well-known statistical definition of the word correlation, so we refer to this as a scoring process.

For cartridge case evidence, first-pass scores are generated separately for each of the basic markings (breech face, firing pin, and ejector mark), using the compressed, small signature associated with an exhibit. This is described as the "crude" correlation,[42] or "coarse" correlation step.[43] The

37. An early application of contact (stylus) measurement of bullet surfaces was the "striagraph" described in J. E. DAVIS, AN INTRODUCTION TO TOOL MARKS, FIREARMS, AND THE STRIAGRAPH (Charles C. Thomas ed., 1958).

38. The potential for the early "striagraph" to damage ballistics evidence was noted in Geoffrey Y. Gardner, *Computer Identification of Bullets*, 11 AFTE J. 26-33 (1979).

39. These noncontact technologies are based on capturing reflected light from a surface; confocal microscopy in particular uses a series of "pinholes" to focus light and to filter out reflected rays that are not directly from the focal point of the source light. For a further discussion, see NAT'L RES. COUNCIL, *supra* note 2, at 190-91, and, VORBURGER ET AL., *supra* note 19, at 33-35.

40. FORENSIC TECH. WAI, INC., IBIS USER GUIDE: VERSION 3.3, at 129 (2001).

41. NAT'L RES. COUNCIL, *supra* note 2, at 103-08 (describing the scoring, ranking, and analysis of signatures in a database).

42. ALAIN BEAUCHAMP & DANNY ROBERGE, MODEL OF THE BEHAVIOR OF THE IBIS CORRELATION SCORES IN A LARGE DATABASE OF CARTRIDGE SCORES 6 (2005) (unpublished manuscript provided to the Committee to Assess the Feasibility, Accuracy, and Technical

coarse comparison scores are ranked from highest to lowest—separately for each type of mark. After the ranks are derived, a threshold is used to select the top few cases. Typically, only the exhibits falling in the top twenty percent in the ranked lists for any of the three markings are retained for further processing. The twenty percent threshold appears to be chosen for computational efficiency. If the reference exhibit does not have an ejector mark image—as is true in some cases—the threshold is based only on the breech face and firing pin images.

The exhibits that were selected from the coarse comparison step are then subjected to a finer comparison based on the full, big signature (described above).[44] The set of scores for the final threshold set of exhibits is then transmitted back to the requesting agency (along with the compressed images, for visual comparison).

For bullets, the process for comparing signatures is different and more complex than cartridge comparison. Since we are not focusing on bullets in this Article, we will forego a discussion of the analysis of bullet signatures.

E. Analysis

The IBIS comparisons provide top-ranked results by any of the marks. For cartridge case, there are three tables, listing the top ten ranked results for each of breech face, firing pin, and ejector/rimfire marks. One can also obtain more detailed reports sorted by one of the score columns, listing the scores for all of the exhibits in the filtered and thresholded exhibit set. The screen can also show the tabular records and side-by-side images of the exhibits. In the side-by-side comparison, the IBIS station essentially emulates the function of a comparison microscope: images can be shifted relative to each other and relative to a center line, directly corresponding to the microscope view, so that striations and patterns can be matched between exhibits. One can also visually compare the reference exhibit and several candidates simultaneously. Two photographic images of the breech face impression using different lighting angles are captured when a cartridge exhibit is entered into the system: a center light image and a side light im-

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Capability of a National Ballistics Database), *available at* http://www.forensictechnology.com/Default.aspx?app=LeadgenDownload&shortpath=docs/LargeDatabaseFinal.pdf.

43. W. George, *A Validation of the Brasscatcher™ Portion of the NIBIN/IBIS™ System*, 36 AFTE J. 286-88 (2004) [hereinafter *Validation of the Brasscatcher Portion*]; W. George, *The Validation of the Brasscatcher™ Portion of the NIBIN/IBIS™ System Part Two: "Fingerprinting Firearms" Reality or Fantasy*, 36 AFTE J. 289-94 (2004) [hereinafter *Validation of the Brasscatcher Portion Part Two*].

44. *See supra* Part II.C.

age. The center light image is the one that is used for scoring, but IBIS operators often prefer the side light image as it can heighten the contrast on specific textures; in IBIS analysis, users may see both center light and side light breech face images as well as the firing pin image.

The basic questions in working with IBIS comparison scores are: (a) how to interpret a particular score, and (b) how deep in a list of sorted results an analyst should look for possible matches. Aside from the basic guidance that "[t]he higher each score is, the more similar the test and reference exhibits are,"[45] IBIS training materials warn against interpreting the system's scores.[46] Users are urged to look for gaps in the distribution of scores—a sharp break between a group of relatively high scores, followed by a marked drop—as one sign of how far to look for possible matches.[47] But the rule of thumb that has endured over time is the advisory to look at the top ten ranks.[48] The focus on the top ten "is not an immutable characteristic of IBIS" but rather "a protocol developed from experience in using the system [that is] open to change as the system changes."[49] "Reviewing the top 10 results has become a NIBIN program standard, though individual practice varies across police departments; for instance, the New York City Police Department (not affiliated with NIBIN) has made viewing the top 24 pairs its standard for cartridge case comparisons."[50] Clearly, the upper bound on the number of pairs that might be examined is the entire set of exhibits that makes it through the full correlation process; more practically, though, the effective upper bound is a function of user fatigue (how many pairs and pages of results a trained IBIS user can effectively examine in a reasonable time).

If examination of the images on screen suggests particularly promising potential "hits," a request for the physical evidence can be initiated so a firearms examiner can compare the exhibits using the comparison microscope.

45. FORENSIC TECH. WAI, INC., *supra* note 40, at 131.
46. *See id.* at 139.
47. *See id.* at 139-40.
48. *See id.* at 139.
49. THOMPSON ET AL., *supra* note 4, at 21.
50. NAT'L RES. COUNCIL, *supra* note 2, at 108.

III. TECHNICAL FEASIBILITY OF A NATIONAL REFERENCE BALLISTIC IMAGE DATABASE

A. Performance Studies of IBIS Two-Dimensional Technology

As the performance of IBIS technology has matured, its performance has been studied by several firearms examiners and other researchers. We provide an overview of the conclusions from several studies.

- The California Department of Justice conducted a study to evaluate the feasibility and utility of a California RBID. The study was based on test firings of 729 similar, bought-as-new firearms: 40-caliber Smith & Wesson Model 4006 semiautomatic pistols.[51] Reporting on the conclusions of the study and an independent external assessment, California Attorney General Lockyer reported that "existing research is too limited and that further study of current and emerging technologies is needed before creating an RBID in California"; this further research should include alternatives such as microstamping and "would be most comprehensive if conducted at the federal level."[52] The report did express optimism on the "potential to develop ballistic imaging into a powerful crime-solving tool," and suggested that "a national RBID could be an extremely valuable tool for law enforcement in generating leads and solving crimes."[53]
- De Kinder et al. describe a follow up study that included a wider range of ammunition. They concluded that "the results of our study illustrate that an RBID cannot adequately and efficiently compare specimens, leading us to conclude that such a database is unsuitable for law enforcement work. The current miss rate identified in this study is unacceptable for an RBID."[54]
- George studied the issue looking specifically at the "coarse" correlation pass and its restriction to the top twenty percent of scores using the small signature.[55] One study documented a high incidence of cases in which known exhibits from the same firearm, even in a relatively small database, were not found in

51. FREDERIC A. TULLENERS, CAL. DEP'T OF JUST., TECHNICAL EVALUATION: FEASIBILITY OF A BALLISTICS IMAGING DATABASE FOR ALL NEW HANDGUN SALES 1-3 (2001).

52. LOCKYER, *supra* note 4.

53. *Id.* at 9.

54. Jan De Kinder et al., *Reference Ballistic Imaging Database Performance*, 140 FORENSIC SCI. INT'L 207, 214-15 (2004).

55. *Validation of the Brasscatcher Portion*, *supra* note 43, at 286-88; *Validation of the Brasscatcher Portion Part Two*, *supra* note 43, at 289-94.

IBIS results because they had been excluded by the coarse correlation step; the follow-up study made use of special permission to completely waive the coarse correlation pass and use complete scoring using the big, fine signatures.

- Nennstiel and Rahm discussed the experience of the Federal Criminal Police Office (BKA) in Germany, which developed its initial IBIS database in 2000 and has added to it since 2001, and contrasted their experience with other available studies of IBIS performance.[56] They concluded: "When operating a collection of evidence ammunition [using IBIS], a success rate *p* in the area of 75-95% for cartridge case comparison and 50-75% for bullet comparison can be achieved in practice under certain conditions. A consideration of the [score] list elements up to *n*-5 or *n*-10 appears to be sufficient. Evaluations that go further increase the workload and contribute little to the improvement in the success rate."[57]
- FTI, the developer and maintainer of IBIS, also conducted a "benchmark evaluation" of IBIS performance for large databases.[58] They used matched pairs of cartridge case exhibits provided by the Allegheny County, Pennsylvania Coroner's Office. Each pair had been fired from the same gun, but the set of guns included a variety of manufacturers and makes within each caliber. The ammunition used in the firings also varied widely and each pair of exhibits did not necessarily use the same ammunition. The results are given in *Ballistic Imaging*.[59] For example, for 9mm guns, with 434 pairs of cartridge cases, there was 53% success in locating sister images based on breech face impressions, 74% based on firing pin impressions, and 84% when they were used together. When additional "noise" casings were added to increase the size of the database to 56,000, the figures dropped to 39%, 53%, and 66% respectively, suggesting considerable degradation in the results. The figures for other gun types were even lower.[60]
- Beauchamp and Roberge extended the benchmark evaluation work, reporting the results of similar IBIS comparisons for two

56. Ruprecht Nennstiel & Joachim Rahm, *An Experience Report Regarding the Performance of the IBIS™ Correlator*, 51 J. FORENSIC SCI. 24 (2006).

57. *Id.* at 28-29.

58. NAT'L RES. COUNCIL, *supra* note 2, 116-20.

59. *See id.* at 120 tbl. 4-2.

60. *Id.*

additional calibers.[61] Their results indicate that when searching a database of 1,000,000 exhibits, IBIS performance in detecting sister pairs within the top ten ranks looking at both breech face and firing pin marks is on the order of 30-35%.[62] Based on the smaller set of 9mm exhibits for which ejector marks were also considered, the estimated success at finding a known match in a 1,000,000-exhibit set is about 50% when all three marks are considered.[63]

B. Panel's Assessment

Our own studies, conducted by NIST under a separate contract with the National Institute of Justice, used two datasets:

- A reanalysis of some of the De Kinder et al.[64] cartridge casings: NIST staff obtained access to the 4,200-element exhibit set analyzed by De Kinder et al., representing firings of seven cartridges in each of 600 SIG Sauer pistols. The NIST study randomly selected ten pistols known to be of the SIG Sauer P226 model and all seven casings for each of those guns were extracted from the exhibit set for further analysis. We refer to this sample of seventy casings as the DKT exhibit set.
- Construction of a new set of test-fired casings by NIST: The "NIST Ballistics Identification Designed Experiment" (NBIDE)[65] restricted attention to 9mm guns and selected three gun models representing a range of perceived quality and precision tooling: Smith & Wesson 9VE, Ruger P95D, SIG Sauer P226. Four new guns from each of these three brands and were purchased. We used three of the same ammunition brands used by De Kinder et al.—Remington, Winchester, and Speer—and added PMC (Eldorado) brand ammunition. The full NBIDE exhibit set has 144 elements: three repetitions of each of four ammunition brands, fired through four guns from each of three makes. However, the NIST analysis uses only a reduced 108-element subset of the exhibits, excluding the Speer brand ammunition firings from analysis. Although only the 108-element

61. BEAUCHAMP & ROBERGE, *supra* note 42.
62. *Id.* at 1.
63. *Id.*
64. De Kinder et al., *supra* note 54, at 207-15.
65. VORBURGER ET AL., *supra* note 19.

set was subjected to three-dimensional analysis, all 144 exhibits were later analyzed using the current IBIS system.

These casings were processed using both IBIS and three-dimensional metrology techniques. IBIS runs on the casing data sets were performed for the panel by the ATF Laboratory, waiving—with assistance from FTI—the coarse comparison and twenty percent threshold steps. Again, to be clear, NIST's three-dimensional analyses on the panel's behalf did not make use of FTI's three-dimensional software and systems—and particularly not the IBIS TRAX-3D system currently being marketed by FTI—as those were just entering development and production. However, the FTI offerings and NIST's approach should share some common underlying technology in confocal microscopy.

First, we describe selected results on top-x lists: whether a casing that matched a reference casing in a database was selected in a top-x list.

1. De Kinder Data

For each of the seventy casings in the De Kinder dataset, there is a group of six other casings that were fired from the same gun and sixty-three casings (nine guns $\times$ seven ammunition brands) that were from other guns. The six casings from the same gun were called "matches" and the remaining sixty-three called "non-matches." The study determined how many of matches were correctly selected in the top ten matching results for selected cases. For example, in Table 1, the ninety-four percent figure for Firing Pin impression in the first column-first row means that ninety-four percent of the seventy IBIS Top Ten lists contained at least one of the remaining six correct casings. Similarly, the seven percent for IBIS 2-D in the first row denotes that only seven percent of the seventy IBIS Top Ten lists contained all six of the remaining six correct casings. The performance measures given in the table for NIST 3-D images show that this 3-D technology outperformed images using the 2-D technology.

Table 1. Matches for DeKinder Data

	At least one match		All six matches	
Impression Type	IBIS 2-D	NIST 3-D	IBIS 2-D	NIST 3-D
Firing Pin	94%	100%	7%	33%
Breech Face	63%	100%	0%	7%

2. *NBIDE Data*

For the NBIDE database, there were twelve guns, three ammunitions, and three days (repeats), and so a similar process yielded comparison of the casing from the first test firing against the 107 (108 – 1) casings from the remaining firings. Of those 107, eight (three ammunition brands × three days – one) are from the same gun as the first test firing, and ninety-nine (eleven guns × three ammunition brands × three days) are from different guns. So, for each casing, there were eight "matches" and ninety-nine "non-matches" in the database. The percentages in Table 2 are in the same format as those for the De Kinder data. The performance for getting for at least one match is quite good but is quite poor in getting all eight matches.

Table 2. Matches for NBIDE Data

	At least one match		All eight matches	
Impression Type	IBIS 2-D	NIST 3-D	IBIS 2-D	NIST 3-D
Firing Pin	96%	100%	0%	23%
Breech Face	99%	100%	6%	94%

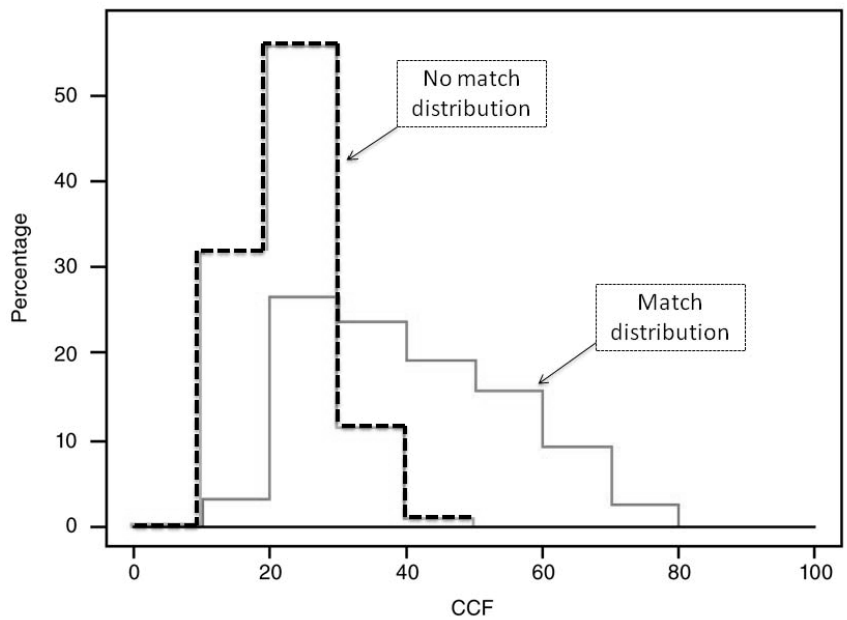
3. *NIST Study Overlap Metric*

The NIST study also derived an *overlap metric* to compare the similarity scores between matching and non-matching exhibits based on three-dimensional topographic images. Specifically, cross-correlation scores for all pairwise comparisons were computed, and the scores were then grouped into two categories: (a) for matching (same-firearm) pairwise comparisons, and (b) non-matching pairwise comparisons.[66] Figure 4 is an illustration of the matching and non-matching histograms for one such case: firing pin impressions for the NBIDE exhibit set. Ideally, the non-matching matching scores will be concentrated near zero, indicating no match, and the matching scores will be at the high end of the range. Further, ideally the matching and non-matching distributions would have no overlap and be wholly distinct from each other. If there is substantial overlap between the matching and non-matching distributions, one can expect a substantial number of false matches, since matches and non-matches become harder to distinguish. In general, the results were better for the NBIDE dataset as

66. NAT'L RES. COUNCIL, *supra* note 2, at 214-15 (describing the NIST overlap metric and how it was used to compare matching and nonmatching distributions of similarity scores).

compared to the De Kinder dataset. Overall, as Figure 4 illustrates, there was considerable overlap in the matching and non-matching distributions.

Figure 4. An example of histogram (distributions) of matching and non-matching pairwise comparison scores for NBIDE firing pin data.[67]



C. Is a National RBID Feasible?

An important issue in assessing feasibility of a national RBID is estimating the size of a national database. The ATF estimates about 4.5 million "new firearms, including, approximately 2 million handguns, are sold in the United States" each year.[68] If we assume, at least initially, that a national RBID would focus on handguns, we can expect between one and two million firearms to be added to the database per year. Our panel also assumed that the test fired exhibits required for entry in the database would consist of expended cartridge cases and not bullets, since the latter are often damaged in crime scenes. In this event, we have to exclude revolvers, which do

67. Redrawn from Vorburger et al. *See* VORBURGER ET AL., *supra* note 19, at 88 fig. 9-6.

68. U.S. BUREAU OF ALCOHOL, TOBACCO & FIREARMS, COMMERCE IN FIREARMS IN THE UNITED STATES 1 (2000).

not automatically expel cartridge casings,[69] and hence, would leave casings at a crime scene only if the gun user manually emptied them at the scene (e.g., to reload).

There are several technical considerations in assessing feasibility. From a database perspective, the panel concluded that current and projected computer capabilities can handle the storage, networking, and information flows associated with such a database readily. The development of a national database is also feasible from a manufacturing perspective. The collection of exhibit casings from newly manufactured firearms should be relatively tractable because, conceptually, all it would require is a systematic, cross-manufacture standardization of current practices of test firing for quality control.[70]

The more challenging issue relates to the effectiveness of the database in providing investigative leads, which depends on the forensics of ballistic images. The results of previous studies as well as those conducted by the panel suggest that the existing imaging methodologies (including the three-dimensional-topography prototype developed by NIST) do not have the discriminatory power needed to reliably place true matches in the top rankings using imaging comparisons. While there is no special magic in top ten or twenty-five thresholds, there is a practical limit in the number of potential matches that any human examiner or operator is likely to page through and consider in his or her work.

As a result, the panel concluded that a national reference ballistic image database of all new and imported guns is not advisable at this time.[71]

IV. MICROSTAMPING: AN ALTERNATIVE TECHNOLOGY FOR TRACING TO POINT OF SALE

A. What is Microstamping?

A goal of searching a ballistic image database is to generate an investigative link from ballistics evidence to the point of sale of the weapon or ammunition used in a crime. Similarly, a firearms examiner's opinion that two pieces of ballistics evidence match suggest a link between the ballistics evidence to the point of sale of the weapon or ammunition used in a crime.

69. NAT'L RES. COUNCIL, *supra* note 2, at 226-27 (describing the rationale behind the panel's assumptions of entering cartridge cases and excluding revolvers).

70. *Id.* at 234-36 (describing the panel's analysis of and conclusions about how the images needed for an RBID could be acquired and entered into the system without being too disruptive to firearms manufacturers).

71. *Id.* at 239.

An entirely different approach, microstamping, could achieve that same goal.

This alternative approach is to place a known, unique, and unalterable identifier on gun parts, cartridge cases, or bullets at the time of manufacture. If such known markings—for instance, a gun-specific alphanumeric code—were logged at the point of sale, a spent cartridge casing recovered at a later crime scene could be rapidly traced back to the point of sale by reading the etched marking. A distinct advantage of microstamping is that the marks could be examined at a crime scene using equipment no more sophisticated than a magnifying glass, vastly simplifying and expediting the process of developing investigative leads. Microstamping, if feasible and practical, would have the advantage of *imposing* uniqueness as a characteristic of ballistics evidence, substituting known and fixed markings for microscopically fine, individualizing characteristics that result from random processes in manufacture and weapon firing.

B. Origins of "Tagging"

The fundamental idea of microstamping—"tagging" or labeling crafted or manufactured items with some identifying mark—has its origins in antiquity when the first artist signed his or her work. Unique "signatures," either literal or representative symbols, have continued to be used to the present day. Over time, manufacturers moved from simple graphic insignia to digital serial numbers due to increasing mass production, the need to accurately track goods during manufacture, and the legal necessity to monitor lot specificity and quality. How serial numbers are applied to objects is as varied as the products produced—bar-coded, machined, cast, painted, or laser-engraved.

Because serial numbers can link manufactured objects to their owners, they provide a valuable tool to law enforcement in developing leads in criminal cases. Two well-known illustrations of the utility of serial numbers in investigating criminal cases are the bombings of the World Trade Center in New York in 1993 and of the Alfred P. Murrah federal office building in Oklahoma City in 1995. Both investigations involved the use of vehicle identification numbers.[72]

Both firearms and ammunition are already subject to conventional serial numbering as manufactured goods. The serial number imprinted on the frame of a firearm can be traced to a point of sale if the weapon is recovered;[73] methods for the restoration of serial numbers that have been defaced

72. *Id.* at 257.
73. *Id.*

by filing or other means are an important part of forensic analysis. Similarly, boxes of ammunition have serial numbers as well.[74] But, in the firearms and ammunition context, microstamping suggests two key novelties. The first is that it could achieve the same basic goal as an RBID—quick investigative leads to the point of sale—because it could link recovered ballistics evidence to that point of sale *without* requiring the recovery of the gun itself. Second—at least conceptually—it could also make bullet evidence quicker to analyze and more useful. If the microstamped marks were etched numerous times on the base of the bullet; the marks would likely survive impact with hard objects like trees or metal doors (in ways that the fine striation marks might not), and the code might be recoverable from even a bullet fragment.

C. Legislation on Microstamping

The California legislature enacted the Crime Gun Identification Act of 2007,[75] and set January 1, 2010, as the effective date of requirements that new semiautomatic pistols sold in the state bear microstamped identifiers. It has not yet been implemented because the inventor of the microstamping technology must free up patent restrictions for the law to take effect.[76] The act requires that a "'microscopic array of characters' that identify the make, model, and serial number of the semiautomatic pistol be etched 'in two or more places on the interior surface or internal working parts' of the gun, for transference to the cartridge case upon firing."[77] A commonly discussed way to do this is to microstamp the tip of the gun's firing pin so that it will impress an imprint on the breech of the cartridge case when the gun is fired.[78] Other jurisdictions have also considered requiring microstamping on guns in previous years, including Connecticut and New York, and an act requiring microstamping on semiautomatic firearms was signed into law in the District of Columbia in March 2009.[79]

At the federal level, the proposed Technological Resource to Assist Criminal Enforcement (TRACE) Act has been offered in several recent U.S. Congresses, but has not advanced beyond subcommittee referral.[80] In the 109th Congress, the act was substantially revised to implement micro-

74. *Id.*
75. CAL. PENAL CODE § 12126(a)(7) (2007).
76. *See* NAT'L RES. COUNCIL, *supra* note 2, at 260.
77. *Id.*
78. *Id.* at 262.
79. *See* D.C. CODE § 7-2505.03 (2010) (effective Jan. 2011); S. 353, Gen. Assemb. Jan. Sess. (Conn. 2009); S. S06005A, A06468C, 2009-2010 Reg. Sess. (N.Y. 2009).
80. NAT'L RES. COUNCIL, *supra* note 2, at 261.

stamping rather than a national RBID.[81] The proposed legislation would forbid the manufacture or import of any "firearm that is not microstamped or a microstamped firearm that does not transfer the array of characters constituting the microstamp onto the cartridge case of any ammunition fired from the firearm."[82] The bill was not enacted in the 109th Congress, and the same legislative text was introduced in the House of Representatives in the 110th Congress.[83] In 2010, a bill was introduced in the House to require a study evaluating the effectiveness of microstamping as a law enforcement tool.[84]

D. Microstamping of Firearm Parts

While microstamping has been proposed for ammunition as well as for guns,[85] we will confine our discussion here to microstamping firearms because it appears to be the more feasible option. The basic concept of microstamping firearms parts is to etch identifier codes into the hard metal components of guns so that when they are fired the markings are impressed on the relatively softer cartridge case or bullet. The early work that has been done in the area has focused on the etching of alphanumeric symbols on the tip of the firing pin.[86] The identifying mark is created when the pin hits the primer surface of the cartridge, and the "image" of the microstamp marking can be read from the firing pin impression on the recovered casing.

In addition to experiments performed by the microstamping technology's developer, NanoMark Technologies,[87] the present technology for microstamping the tip of firing pins has been tested by two firearms examiners. Haag[88] submitted four firing pins to the developer for microstamping: three of them were for a machine gun or automatic rifle, intended to test the durability of the microstamp engraving over large numbers of firings.[89] He found that the marks were generally durable and left readable codes after 2500 firings. Krivosta was more cautionary. He observed that "a number

81. *Id.*

82. *Id.*

83. *Id.*

84. Firearms Microstamping Evaluation and Study Act, H.R. 5667, 111th Cong. (2010), *available at* http://www.govtrack.us/congress/bill.xpd?bill=h111-5667.

85. NAT'L RES. COUNCIL, *supra* note 2, at 267-71.

86. *Id.* at 262.

87. *Id.* at 263.

88. Lucien C. Haag, Criminalist, Forensic Sci. Servs., Ballistic ID Tagging, Presentation to the Committee on the Feasibility, Accuracy, and Technical Capability of a National Ballistics Database (Dec. 2004).

89. *See id.*

of test fires" from a Remington .22 Long Rifle semiautomatic rifle were illegible.[90]

"Conceptually, the microstamping of firearms parts . . . has several potential advantages for forensic identification."[91] First, "assuming that the microstamped identifier is clearly impressed on spent casings," it can be viewed using microscopes already present in standard laboratories.[92] In some cases, identifiers might even be "read at crime scenes using a hand magnifying lens."[93] Second, "the machinery used to perform the etching" on the firearm parts "is not highly specialized."[94] Third, "more than one microstamped identifier could be placed on different areas of the gun's firing assembly to increase the likelihood that at least one identifiable mark will be imparted on cartridge case or bullet evidence."[95] As mentioned above, one conceptual novelty of microstamped bullets is that, by repeating the identifier multiple times, an identifiable mark could survive the fragmentation of a bullet. And finally, "placing recessed characters on the firing pin, and perhaps adding a microstamped identifier elsewhere, would make it more difficult to deface or remove the identifiers without rendering the gun inoperable."[96]

On the other hand, there are also significant "conceptual disadvantages of microstamping firearms parts, particularly the firing pin."[97] First, "barring a radical (and likely untenable) legislative requirement prohibiting use of *any* firearm [including existing ones] without a microstamped identifier, the coverage of firearms microstamping would include only *new* firearms" so that "the millions of firearms currently in circulation would not be affected."[98] Second, "microstamping strategies that only [put] identifiers on cartridge casings would not be effective in solving crimes involving revolvers."[99] And "such strategies would also be hindered in instances in which suspects remove spent casings from semi-automatic weapons from crime scenes."[100] Third, firing pins can be easily replaced

90. George G. Krivosta, *NanoTag™ Markings From Another Perspective*, 38 AFTE J. 41, 47 (2006).
91. NAT'L RES. COUNCIL, *supra* note 2, at 265.
92. *Id.*
93. *Id.*
94. *Id.*
95. *Id.*
96. *Id.* at 266 (discussing these potential advantages).
97. *Id.*
98. *Id.* (emphasis added).
99. *Id.*
100. *Id.*

> so a single microstamped identifier could be defeated by swapping in a new pin. Working around this would require that newly manufactured firearms *parts* have to bear an identifier, and that this information would have to be logged at time of sale and maintained on file.[101]

Fourth, Krivosta subjected a microstamped firing pin to "intentional defacement": a process "easily accomplished in approximately one minute's time" using a sharpening stone and a portable drill.[102] The removal of the microstamped identifier in this case did not impede the ability of the gun to fire. Last but not least, "[e]stimates of the per-unit cost to place a microstamp tag vary widely."[103]

> Proponents of microstamping suggest that the cost of marking a firing pin would be between $0.50 and $1.00, with some [] estimates as low as $0.15. However, opponents claim the cost to be closer to $150, perhaps taking into account the initial capitalization needed to obtain and operate the equipment or to change production flows so that component parts are stamped.[104]

E. Assessment of the Microstamping Option

We believe that both the microstamping of firearms parts and ammunition possess the formidable conceptual advantage of imposing discernible and objective uniqueness on bullet or cartridge case evidence. Thus, microstamping could provide a stronger basis for identification based on the evidence than the status quo, positing that uniqueness arises from random microscopic phenomena and assuming that unique features manifest themselves in different imaging media.

It is also abundantly clear that substantial further research would be necessary to inform a thorough assessment of the viability of microstamping either gun parts or ammunition. The topics of this research include the reliability and durability of the marks in a variety of firing conditions, their susceptibility to tampering and countermeasures, a decision on whether to place them on guns or ammunition or both, and the cost implications and feasibility of adding a microstamping process to established manufacturing processes. Particularly important would be credible estimates of the real cost of implementation, separating initial configuration costs from other life-cycle costs, that accurately take into account the reengineering of existing firearms and ammunition production lines.

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101. *Id.*

102. Krivosta, *supra* note 90, at 41-47.

103. NAT'L RES. COUNCIL, *supra* note 2, at 266.

104. *Id.* at 266-67 (citing Jason Tsai, *Etched Bullets Interest Law Enforcement; Lasering May Help Solve Gun Crimes*, BERGEN CNTY. RECORD, Sept. 25, 2006, at A1).

CONCLUSION

The validity of the fundamental assumptions of uniqueness and reproducibility of firearms-related toolmarks has not yet been fully demonstrated. Notwithstanding this fact, we accept a minimal baseline standard regarding ballistics evidence. Although they are subject to numerous sources of variability, firearms-related toolmarks are not completely random and volatile; one can find similar marks on bullets and cartridge cases from the same gun.[105] And, imaging technology can capture much of the information that the toolmarks leave on bullets and cartridge casings after firing a weapon.

The existing NIBIN system is limited to pieces of ballistics evidence recovered at crime scenes or test fired from weapons recovered by the police. Even with that limitation, it has allowed many law enforcement agencies to effectively use images of ballistics evidence to generate investigative leads. For that reason, *Ballistic Imaging* recommends that the NIBIN system be retained and improved.[106]

However, we concluded that a much larger version, a national RBID containing images of exhibits fired from all newly manufactured and imported guns, is not feasible or operationally useful;[107] that is, a national RBID would not be a useful tool for generating leads for follow-up and further investigation. With additional research and improvements in imaging technologies, this may change.

Finally, microstamping firearms parts and ammunition is conceptually very attractive because of the objective uniqueness of the signature it puts on bullet or cartridge case evidence. But this technology is still in the pilot stage. Substantial further research and development on the viability of microstamping either gun parts or ammunition is needed to determine whether this approach is a practical and usable alternative to the status quo.

105. *See* NAT'L RES. COUNCIL, *supra* note 2, at 81-82.

106. *See id.* at 162-85 (describing the Committee's recommendations for improving the NIBIN system and the reasoning and evidence supporting them).

107. *See id.* at 239-41.