Evaluation of GLOCK 9mm Firing Pin Aperture Shear Mark Individuality Based On 1,632 Different Pistols by Traditional Pattern Matching and IBIS Pattern Recognition


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ABSTRACT: Over a period of 21 years, a number of fired GLOCK cartridge cases have been evaluated. A total of 1,632 GLOCK firearms were used to generate a sample of the same size. Our research hypothesis was that by comparing only firing pin aperture shear marks no cartridge cases fired from different 9 mm semi-automatic GLOCK pistols would be mistaken as coming from the same gun. Using optical comparison microscopy, two separate experiments were carried out to test this hypothesis. A sub-sample of 617 test fired cases were subjected to algorithmic comparison by the Integrated Ballistics Identification System (IBIS). The second experiment subjected the full set of 1,632 cases to manual comparisons using traditional pattern matching. None of the cartridge cases were "matched" by either of these two experiments. Using these empirical findings, an established Bayesian probability model was used to estimate the chance that a 9-mm cartridge case could be mistaken as coming from the same firearm when in fact it did not (i.e. the random match probability).

Key Words: Forensic Science, Daubert, firearms identification, fired cartridge cases, microscopic examination, IBIS, false match rate, random match probability, legal challenges, pattern matching, Glock, firing pin aperture shear marks.
Since 1925, forensic examiners have used optical comparison microscopy to examine firearm and toolmark evidence (1). For fired cartridge cases, the trained firearm examiner microscopically evaluates the fine scratches (striae) and impressions (or "features") found on bearing surfaces, and discriminates between individual features that randomly occur and toolmarks imparted during the manufacturing process (2, 3). Individual features that are determined to occur at random form a pattern unique to a specific firearm. Moran provides excellent information concerning the AFTE Theory of Identification and Range of Conclusions used by the trained firearms examiner community (2). We also note that firearm and toolmark identifications can always be – and quite often are, as required in most accredited laboratories – verified by another qualified examiner.

In order to test the hypothesis that individual random features found on fired bullets and cartridge cases are unique to the specific firearm that imparted them, extensive empirical research has been conducted and reported on for the past 100+ years. Three excellent references by Ronald Nichols, including a presentation at the ATF Laboratory in California (5-7), comprise a very comprehensive review of the literature that pertains to firearm and toolmark identification criteria. In 2011, Petraco, a senior forensic scientist retired from the New York Police Department Crime Laboratory, authored a textbook covering the collection and examination of impression evidence based on AFTE training materials. This reference book has been well received in the forensic and academic communities (8,9). Additional articles by Grzybowski et al. and Biasotti et al. (10-12) offer a valuable compendium of reference materials that discuss scientific methods and the reliability and validity of the field of firearm and toolmark identification. The following research articles – briefly discussed in chronological order – reflect only a small amount of research that has been conducted for cartridge cases.

In 1907, the first recorded examination of multiple firearms in conjunction with fired cartridge cases involved inspectors at the US Army’s Frankford Arsenal. The arsenal staff
examined 279 30-caliber service rifles and 33 fired cartridge cases from a shooting incident in Brownsville, Texas. The rifles were test fired and the resulting test cases were examined in conjunction with the evidence cases. The staff reported that they were able to identify some of the fired cartridge cases to their corresponding rifles. Their conclusions are an excellent example of early cartridge case identifications (13-15). Additional research continued in the forensic field during the next twenty-five years by early self-trained examiners such as Sir Sydney Smith and Robert Churchill, both from the United Kingdom, and Dr. Calvin Goddard from the United States, as well as several others. Four heavily-reported criminal events permanently established the discipline of firearm and toolmark identification both in the United Kingdom and United States. These cases involved the assassination of the Sidar in Egypt, the murder of Constable Gutteridge in England, the Sacco-Vanzetti murder case, and the St. Valentine’s Day Massacre in the United States (16-18). The ability of these pioneer examiners to identify cartridge cases, as well as fired bullets, to a specific firearm was instrumental in establishing firearm and toolmark identification as one of the forensic sciences.

Numerous studies support the contention of uniqueness where multiple bullets and/or cartridge cases are fired from one firearm. In 1957, Flynn reported on a study where the then Chicago Police Department (CPD) Crime Lab examined a total of 100 consecutively manufactured chisels that had been finished using a grinding process. He reported that a total of 5,050 total comparisons were made during the experiment with no misidentifications (19). In 1958, Kirby from the RCMP Laboratory in Canada fired 900 lead bullets from a .455 caliber revolver and was able to identify that all of the cartridge cases had been fired in the same firearm (20).

In a study conducted in 1972, one of the authors (Hamby), then at the US Army Criminal Investigation Laboratory (USACIL), fired 501 .223 caliber (5.56mm) full metal jacket (FMJ) projectiles from an M16A1 assault rifle (21). The 501 cartridges were fired as
fast as the 20 round magazines could be changed and every hundredth bullet collected in a cotton recovery box. Using a standard optical comparison microscope, it was possible to identify all the bullets as having been fired in the same rifle. Further microscopic examinations also revealed that all of the cartridge cases had been fired from the same rifle. The identifications of the fired bullets and cartridge cases were verified by a second qualified firearm examiner.

Ogihara et al. conducted an extensive research study in 1977, by examining 5000 bullets and cartridge cases fired from an U.S. Army issue M1911A1 .45 ACP (11.45mm) caliber semiautomatic pistol (22). The researchers used standard .45 caliber FMJ military ammunition for the project and collected every 10th fired bullet and cartridge case for their examination. This study involved firearm examiners from three different forensic laboratories located in Japan and required a substantial amount of time to perform the comparisons for both the bullets and cartridge cases. Using standard optical comparison microscopic techniques in conjunction with traditional pattern matching, the researchers were able to identify that all 5,000 bullets and cartridge cases had been fired from the same pistol.

In 1983, Shem and Striupaitis, then with the Illinois State Police Laboratory, fired 501 bullets and cartridge cases from a Raven Model P-25 .25 caliber (6.25mm) ACP caliber semiautomatic pistol. They collected every 10th fired projectile and cartridge case and examined them. They concluded that, although changes were occurring in the bullet and breechface striae, it was possible to identify both bullet and cartridge case 1 to 501 (23). In 1984, Matty and Johnson, both from California Department of Justice Laboratories, examined the concentric marks produced by Smith & Wesson firing pins. Subclass characteristics were found as a result of the lathe-mounted cutter used to shape the firing pins being much harder than the metal used to make the firing pins. They determined that areas of the firing pins that show wear can be used for identification (24).
Matty conducted another study in 1984 involving three consecutively made breechfaces from Raven semiautomatic pistols. His observations were that the concentric toolmarks on the breechfaces could be individualized and that they were not subclass (25). In 1994, Thompson, then with the Indianapolis-Marion County Forensic Services Agency reported on a follow-up study of the article by Matty on Raven breechfaces. He compared four breechfaces from Phoenix pistols (formerly Raven). His examination confirmed the findings of Matty that these breechfaces possess unique identifying marks (26).

Uchiyama, from the National Research Institute of Police Science in Japan, conducted a study in 1986 where he examined the breechface marks produced by .25 caliber Browning, Raven, and Titan semiautomatic pistols. He determined that subclass characteristics, due to the manufacturing process, were significant and informed examiners to be cautious when examining these types of firearms (27).

In 1992, Schecter et al. from the Israel National Police Laboratory, test fired a new .223 caliber (5.56mm) GALIL rifle 7,100 times using a variety of .223 caliber ammunition. They then microscopically examined the ejector markings on the fired cartridge cases (the ejector on a GALIL rifle is part of the rifle and not removable). They were able to identify the ejector marks form the 9th test fired cartridge case through the through the 7,060 test firing (28).

In an excellent article by Bonfanti and De Kinder (29), they discuss several scientific studies (some mentioned in this article) that have been conducted where fired bullets and/or cartridge cases have been examined after test firings from consecutively manufactured items. In other instances, research has been conducted to evaluate fired components from a large number of firearms.

In 2000, Lopez and Grew from the FBI Laboratory conducted a study involving firearm bolt faces machined with an end mill. Their study warns that a misidentification is possible unless the identification is based on breechface wear or machining “chatter” marks
on the breechface (30). Further studies by Bunch and Murphy from the FBI Laboratory reported in 2003 on a study where they obtained 10 consecutively manufactured GLOCK semi-automatic pistol slides at a factory in Austria. The manufacturing process of the 10 slides - which contain the breechface - was observed and the slides then used to produce test-fired cartridge cases for a comprehensive validity study by members of the FBI Laboratory’s Firearms-Toolmark Unit (FTU). Using breechface markings, the examiners were able to identify the fired cartridge cases to their respective slides (31).

Vinci et al. conducted an extensive study in 2004 where they fired 2500 cartridges from a .45 ACP (11.45mm) caliber Springfield Armory semi-automatic pistol. They examined every 100th fired cartridge case to evaluate sequential changes in both class and individual characteristics and reported that it was possible to identify all 2500 cases as having been fired from the recently produced pistol (32).

Smith from the FBI Laboratory reported on a research study in 2005 that was designed to test the accuracy of examinations by trained firearm examiners who use pattern recognition as a method for identification. Eight FBI examiners took the test, which consisted of both bullets and cartridge cases. No false positives or false negatives were reported (33).

In 2008, Gouwe from the Botswana National Police Laboratory, along with two of the current authors (Hamby and Norris), reported on a experiment where they fired a total of 10,000 .40 S&W caliber cases from one GLOCK Model 22 firearm. They microscopically examined every 10th case to determine if sufficient identifiable impressed and/or striated markings were present for identification. They determined that sufficient individual markings were present on the fired cases to identify casing #1 to casing #10,000 (34).

In 2010, Lightstone, from the Washington DC Metropolitan Police Department, reported the results of her experimentation with consecutively manufactured Smith & Wesson pistol slides. She examined the breechface markings left on fired cartridge cases and
determined that some subclass marks were present. She determined that although subclass marks did exist on some of the fired cases, a qualified examiner would be able to identify them to the correct pistol slide (35).

In 2011, LaPorte, from the Pasadena (Texas) Police Department Crime Laboratory, conducted an empirical and validation study involving breechface marks on .380 ACP (9mm Kurz) caliber Hi-Point pistols. The slides that contain the breechface marks were consecutively manufactured and then test fired using three (3) brands of ammunition. The fired cartridge cases were examined in conjunction with each other and she determined that the machining performed on the breechfaces during manufacture provides unique and individual marks for identification purposes (36).

Gambino et al. in 2011 conducted a pilot study involving primer shear "profiles" on 9mm cartridge cases, fired from four Glock model 19 pistols. The 3D surfaces were collected using high-resolution white light confocal microscopy and the resulting 3D topographies were filtered to extract all “waviness surfaces”—the essential “line” information that firearm and tool mark examiners view under a microscope. Extracted waviness profiles were processed with the computational pattern recognition techniques of principal component analysis (PCA) and support vector machines (SVM). Bootstrap-based error rates were found to be 0%, indicating that the error rate for the algorithmic procedure is likely to remain low on larger data sets. The study also described how conformal prediction theory (CPT) could be used to establish rigorous levels of confidence for algorithm designated "matches" and suggestions were made for practical courtroom presentation (37).

In 2012, Mikko, Miller, and Flater from the USACIL, now at Forest Park, Georgia, conducted a study involving the reproducibility of striated markings on 20,000 bullets fired from a M240 Machine Gun (standard issue for the US Army). The M240 Machine Gun is chambered for the caliber 7.62x51mm NATO cartridge. During their examinations, they did note some changes in the amount of striations present on the series of test-fired bullets, but
concluded that sufficient individual striations existed on the entire group of test fires to enable examiners to identify them as having been fired through the M240’s barrel. They stated that a future article would discuss their evaluation of the 20,000 fired cartridge cases (38).

In 2013, Monkres et al. performed a study in an attempt to confirm an examiner’s conclusions through objective computer analysis. The researchers used known and unknown bullets fired from consecutively manufactured barrels which were then examined through optical comparison microscopy. All the land impressions designated as L1 on the bullets were photographed and measured. The measurements were converted into barcodes and subjected to Principle Component Analysis (PCA). A Support Vector Machine (SVM) was employed to evaluate the computer’s ability to correctly identify which L1 was represented by the barcode. They determined that the computer was able to adequately group barcodes according to their common origins, supporting the examiner’s identifications (39).

In this study, using only firing pin aperture shear marks, the authors explore the likelihood of whether or not cartridge cases fired from different model GLOCK semi-automatic 9mm pistols might be incorrectly matched to the wrong firearm by a qualified firearms examiner or the IBIS computer-aided identification system. That is, the operating hypothesis of this study is that by using only firing pin aperture shear marks, no cartridge cases fired from different 9 mm semi-automatic Glock pistols should be determined to match each other, either by a trained firearms examiner (not using quantitative consecutive matching striae tabulation) or machine comparison (IBIS). Glocks are ideal in the sense that they are very well known to generally produce well-defined firing pin aperture shear marks on the primer of cartridge cases fired from them. Thus a false match rate estimate on these relatively well-defined firing pin aperture shear marks provides a “baseline” on the false match rate for more difficult toolmark comparisons.
Given the empirical findings detailed below, an established Bayesian model was then employed to estimate the probability of falsely matching an expended 9mm cartridge case from a semi-automatic pistol that did not fire it (40). Such an error rate estimate is the type of "quality assurance" embodied in the Daubert standard.

**Methodology**

Over a one-month period in 1997, six hundred and seventeen (617) 9mm Glock pistols (varying models) were test-fired at the then Indianapolis Police Department (IPD) Range to obtain fired cartridge cases for evaluation. The pistols were test fired, and the cartridge cases collected into envelopes with randomly assigned control numbers from 1 to 617. The cartridge cases were subsequently removed from each envelope, scribed with the assigned control numbers, and placed in plastic ammunition trays for examination.

The firing pin aperture shear marks of 617 fired cartridge cases were imaged into the laboratory’s Integrated Ballistics Identification System (IBIS) by Specialist John Brooks. A request was made to Forensic Technology, Inc., Montreal, Canada to perform correlations to determine if any of the cases "matched" to each other (i.e. misidentified to one another) based on the IBIS correlation score. These examinations involved a total of \((617 \times 616)/2 = 190,036\) pair-wise comparisons by the IBIS correlation algorithm. Again, the study's hypothesis is that none of these cartridge cases should be determined to have sufficient microscopic agreement for association to each other as they were all fired from different 9mm pistols.

A second microscopic examination of the firing pin aperture shear marks by two trained firearms examiners was then carried out on this original set of 617 cases, as well as two more groups of cartridge cases collected over the next decade and a half. The first of these groups consisted of seven hundred (700) test fired 9mm cartridge cases obtained from GLOCK, Inc. over a five-year period as part of their quality assurance program. The second
of these groups consisted of three hundred and fifteen (315) recently fired GLOCK cartridge cases – including twelve (12) from consecutively manufactured slides. These cases were aggregated with the original sample of 617 from 1997 and collectively examined using a Leica Model K-2700 comparison microscope, an American Optical Model K-1453 Forensic Comparison Microscope, and a Leica Model DMC Forensic Comparison Microscope. The protocol was as follows: the first cartridge case was designated as the primary case and placed on the left side of the comparison microscope. Using the right side of the comparison microscope, the remaining 1,631 fired cases were compared to the primary cartridge case until all 1,632 cases were examined. After cartridge case number 1 was examined against the other cartridge cases, the entire process started again. Case 2 was then examined against the other 1,630 and so forth until all cases were examined against each other. This resulted in \((1632 \times 1631)/2 = 1,330,896\) unique pair-wise comparisons by a trained forensic firearms examiner. For reference, Figures 1 and 2 show examples of both a "non-match" and a "match" for 9 mm Glock pistol firing pin aperture shear marks.

FIG 1. Example of a 9-mm Glock firing pin aperture mark non-match
**Statistics**

In this study we are interested in estimating the chances that two different firing pin aperture shear marks on cartridge cases fired from two different 9-mm Glocks would be assessed as having been fired from the same 9-mm Glock. We refer to such a circumstance as a "false match". From a computational pattern recognition point of view, the human examiner or the IBIS is playing the role of a “classifier” (41). Thus rephrasing slightly, we wish to estimate the “classifiers” expected false match rate (FMR. Also called probability of a false match and random match probability. Cf. Saunders 2011 (42)). We would like to have a measure of uncertainty in our estimate with some given level of probability (i.e. an interval estimate around the expected FMR) as well.

Typically, in a study of this design, a frequentist-based approach is used to estimate the FMR, which exploits the binomial distribution (43). This is problematic for two main reasons: first, no false matches were observed in this study (discussed below) and thus barring ad-hoc techniques, no interval estimates for FMR are possible. Second, when multiple firearms are tested multiple times, the binomial model can underestimate variability (43,44). This is true not only in our case, but in any design using pair-wise comparisons (41).

This is where Bayesian methodology can be of some assistance. All unknowns are treated as random variables in Bayesian statistics. “Knowledge” in quantities of interest is represented as probability distributions. A Bayesian technique takes what is “known” or
“believed” about an unknown parameter (FMR in our case) and represents it as a prior distribution. Then, by updating this with data via a likelihood function one obtains a posterior distribution on the parameter(s) of interest. Everything we currently “know” about the parameter (FMR for this study) in light of data from the experiment is summarized by its posterior distribution. Bayes theorem can be compactly expressed in our situation as:

\[ p(FMR|data) = \frac{p(data|FMR)}{p(data)} p(FMR). \]

On the left hand side is the posterior for FMR. The “data” in our case are the results of the human/IBIS comparisons. The rightmost term is the prior distribution for our belief as to what the FMR is before seeing the experimental data. Here we would like to assume little and take the prior to be fairly uniform on the interval [0,1]. The term in the denominator is often referred to as the “evidence” and is difficult to compute directly. However, with the technique we will employ for this study (Markov Chain Monty Carlo sampling), it can be ignored. The remaining term on the right hand side is the data likelihood function. Schuckers has noted that for this type of study design, a Beta-binomial model for the likelihood function can incorporate extravariation not accounted for in the binomial model which assumes statistically independent comparisons (40,41). Couched in Bayes’ theorem, Schuckers method also allows us to give an interval estimate of uncertainty around the posterior FMR (40).

Specifically, let \( n \) be the number of comparisons the examiner (human or machine) conducted and \( x \) the number of false matches made. Table 1 lists \( n \) and \( x \) for each of the two experiments.
TABLE 1—Results of comparison experiments.

<table>
<thead>
<tr>
<th></th>
<th>IBIS Comparisons(^a)</th>
<th>Human Examiner Comparisons(^a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample size</td>
<td>617</td>
<td>1,632</td>
</tr>
<tr>
<td>(n)(^b)</td>
<td>190,036</td>
<td>1,330,896</td>
</tr>
<tr>
<td>(x)(^c)</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

\(^a\)See Methodology section for experiment details.

\(^b\)The number of comparisons made in the experiment.

\(^c\)The number of false matches for the experiment.

As Schuckers describes in (40), each comparison the examiner (classifier) executes is a (possibly correlated) Bernoulli trial with a probability of a false match (i.e. a “success”) \(p\).

The number of false matches \(x\) is modeled as a binomial distribution

\[
x \sim \text{Bin}(n, p) = \binom{n}{x} p^x (1 - p)^{n-x}.
\]

We model the \(p\) (FMR) as a Beta distribution with parameters \(\alpha\) and \(\beta\)

\[
p \sim \text{Beta}(\alpha, \beta) = \frac{\Gamma(\alpha+\beta)}{\Gamma(\alpha)\Gamma(\beta)} p^{\alpha-1} (1 - p)^{\beta-1}.
\]

The joint distribution is then

\[
p(x, p) = \text{Bin}(n, p) \text{Beta}(\alpha, \beta).
\]

This will allow us to “kill two birds with one stone”. Knowledge of \(\alpha\) and \(\beta\) gives us knowledge of \(p\). Also, by integrating out (averaging over) \(p\), we are left with a likelihood function for the data, \(x\). Luckily the integral is well known and just yields the Beta-Binomial distribution (40):

\[
\int p(x, p) dp = p(x | \alpha, \beta) = \text{BetaBin}(x_i | \alpha, \beta) = \left( \frac{\Gamma(\alpha+\beta)}{\Gamma(\alpha)\Gamma(\beta)} \right) \frac{\Gamma(\alpha + x_i)\Gamma(\beta + n + x_i)}{\Gamma(\alpha + \beta + n)}
\]
At this point we seem to have replaced what we were really interested in, the FMR ($p$) with $\alpha$ and $\beta$. However the posterior distributions of these parameters give us the posterior distribution of the FMR:

$$FMR = \frac{\alpha}{\alpha + \beta}$$

The variance of the Beta-binomial likelihood function allows for greater variability in $x$ (and FMR as a consequence) by virtue of its increased variance over the binomial model (40). By placing suitable priors on $\alpha$ and $\beta$ which reflect our prior assumptions/beliefs about $p$, (i.e. that it’s somewhere between 0 and 1, but we are fairly ignorant about it) we can use Bayes’ theorem to obtain posterior samples of $\alpha$ and $\beta$ and thus the posterior distribution of FMR.

Following Schuckers, we use truncated Gaussian priors for $\alpha$ and $\beta$. Gaussians are proper probability densities (i.e. normalizable, though this is not strictly necessary), and we truncate them because $\alpha > 0$ and $\beta > 0$ for the Beta distribution. The hyper-means ($\mu$) and standard deviations ($\sigma$) for $\alpha$ and $\beta$ were chosen such that the (implied) prior for FMR was fairly uninformative, with the probability spread between 0% and 100%. Figure 3 shows a simulation of the prior for FMR with $\mu_\alpha = \mu_\beta = 1 \times 10^6$ and $\sigma_\alpha = \sigma_\beta = 1 \times 10^6$. It is fairly uninformative with a mean prior FMR of about 50%.
FIG 3. Simulation of prior distribution for false match rate, based on chosen hyperparameters for $\mu_\alpha$, $\mu_\beta$, $\sigma_\alpha$ and $\sigma_\beta$.

We sampled from the posterior using the general Markov chain Monte-Carlo software JAGS (45). Four chains were used with 10,000 iterations each. The first 5,000 iterations of each chain were treated as burn-ins and thrown away. R-hat convergence diagnostics were all 1.0 (the chains are effectively converged) (46). The remaining samples were thinned by keeping every 5th sample only. A total of 4,000 (marginal) samples for $\alpha$ and $\beta$ were thus (approximately) drawn from the posterior. With a posterior sample of $\alpha$ and $\beta$ in hand, the probability of a false match was computed by the equation above.

Results and Discussion

The original set of 617 fired cases were digitally imaged and entered into the Integrated Ballistics Identification System (IBIS) for correlation against each other. It was found that the instrument had the capacity and capability to handle the number of cartridge cases and to achieve zero misidentifications. Mike McLean from FTI provided the following information concerning their evaluation. He stated “…Forensic Technology (FTI) was provided test results from 617 test fired exhibits from 617 different GLOCK pistols. FTI then
imaged and correlated all of these samples against one another in order to see if any matches were among these samples. It was found that none of the 617 Test Samples were matches to one another…” (M. McLean, personnel communication, June 1992).

Regarding the optical comparison microscopy comparisons, each of the 1,632 fired cartridge cases examined by a human could be seen to have their own individual characteristics. The cartridge cases were therefore individualized within their own set of 1,632 fired cases – to the absolute exclusion of the remaining cartridge cases. Thus, using pattern matching identification criteria with optical comparison microscopy, a trained firearms examiner was able to determine that each cartridge case had firing pin aperture striae that would not be mistakenly associated with another.

Figure 3 shows a simulation from our prior probability assumption for the FMR. Note all probabilities are quoted in percentages. This prior is derived from priors for the $\alpha$ and $\beta$ parameters of the Beta-binominal distribution. The priors for those parameters are fixed (i.e. they are hyper-parameters) and were chosen such that the prior for FMR was relatively uninformative.

As can be seen from Figure 3, the prior peaked around an FMR of 50% with significant probability mass spread from about 0% to about 100%. Figure 4 shows the posterior distribution for the FMR given the IBIS data. The histogram shows the (posterior) probability of a false match for the IBIS experiment to be $5 \times 10^{-4}$ % (95% credibility interval: $[1 \times 10^{-5} \%, 2 \times 10^{-3} \%]$) (sample size = 617).
FIG 4. Posterior distribution for false match rate given the IBIS data only.

Next, Figure 5 shows the posterior distribution human-based examination data (sample size = 1,632). From the computation we find a false match probability estimate of $1 \times 10^{-4}\%$ (95% credibility interval: $[3 \times 10^{-6}\%, \ 4 \times 10^{-4}\%]$).

FIG 5. Posterior distribution for false match rate given both the IBIS data and examiner data.

From these studies, given the false match rate model, we can then infer that the probability of two different 9mm semi-automatic Glocks producing firing pin aperture shear marks that
could be mistaken as coming from the same Glock is miniscule and on the order of about $10^{-4}$ % or less.

**Conclusion**

Forensic firearms examiners have routinely identified or excluded fired bullets and cartridge cases with suspect firearms over the past 100+ years. This research project, involving the comparison of fired cartridge cases against each other, empirically validated the premise that each was identifiable and unique. An upper limit to a random match probability for this group of firing pin aperture marks on fired cartridge cases was estimated to be 0.0001 % based on these findings. Although no firearm-to-cartridge case identifications were made in this research, it does support the concept of identifying fired cartridge cases to the firearm that fired them and should be of value in supporting the existing basis for firearm and toolmark identification.

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Additional information, supplementary material and reprint requests:

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