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STRIAE REPRODUCIBILITY ON SECTIONAL CUTS OF ONE THOMPSON CONTENDER BARREL

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ABSTRACT

The purpose of this study was to determine the persistence of reproducible striae on bullets after removal of one-inch barrel sections. The comparison of striae left on bullets from adjacent sections of such a barrel is analogous to the comparison of striae from consecutively produced barrels. Wire electron discharge machining was the method of choice for cutting the barrel sections leaving no visible burs under high magnification. A total of six one-inch sections were removed. Bullets test fired from a section were first compared to each other and then to bullets test fired from adjacent sections. These comparisons utilized an objective methodology for comparison, which consisted of tabulating the number of lines, number of matching lines, and number of consecutive matching[1] lines for each land and groove impression. Percent match[1], average striae count, and the probability of finding at least one event (single, double, triple, etc.) in a land or groove impression were subsequently calculated. The results of the study show that striae on bullets were significantly altered by the removal of the one-inch barrel sections.

BACKGROUND

In the area of firearms identification, firearms examiners frequently want to look at consecutively rifled barrels to see if there is any carry over of sub class features. If there is not, this would ensure that the striations they see on bullets fired from similarly rifled gun barrels are unique and not reproducible between barrels. While a barrel may be consecutively rifled, there are generally no guarantees that the barrel in question has been drilled and reamed by the same tool. Thus, an ideal method of removing such a variable would be to look at one barrel and determine the persistence or lack of persistence of striations that can be matched over the length of the barrel. Using one barrel eliminates the variables that may be caused by different tools being used for the drilling, reaming and honing operations. Thus the only variable is the striations imparted by the rifling, reaming and honing operation.

Other researchers[1] have evaluated sets of consecutively rifled gun barrels, but the lack of objective criteria makes it difficult to translate what these examiners have observed. A method of providing some objective criteria first proposed by A. Biasotti[2] was utilized for this study. This methodology provides objective criteria that can be documented and validated by independent researchers.

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[1] *Matching lines* is a term used for brevity to denote matching striae either consecutive or non-consecutive which have a unique character, i.e. width, height, length and contour.
Percent matching lines denotes the percent of matching striae without regard to consecutiveness.
Consecutively matching lines are striae that correspond or match with respect to each striae's width, depth and contour and are sufficient length to assure that striae are parallel to one another. The term striae is more commonly used than lines because the latter term is reserved for striae that are very shallow and thus appear virtually two dimensional
[2]Biasotti A. & Murdock J. Firearms and Toolmark Identification Chapter 19, "The West Companion to Scientific Evidence August 1997, p30.

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Biasotti's research led to the determination of probabilities of consecutive matching striae, an example of which is illustrated in figure 1. He used several criteria for the evaluation of striae in toolmarks. The students who assisted in performing the present research used these criteria when comparing the land and groove impressions. When making striae counts, a line must be persistent across the field of view to be counted as a line. The persistence of a line was used to help evaluate the reproducibility of the line. A striae that is not reproduced from toolmark to toolmark is not valuable in comparisons. This is the reason that very short and very fine striae were not included in students' striae counts. Striae were considered to match when the bullets were in phase, when the striae were parallel with the land or groove impression, and when similar in contour and persistence. The width, depth and shape of the line define contour. Two striae that were at the same position in a mark, but had different width were not counted as matching. The use of these criteria made the comparisons less subjective and enabled the students to achieve similar results.

BARREL SELECTION

A Thompson Contender barrel was selected for this study because: 1) it was long enough to remove multiple small barrel sections and 2) it was rifled using the button swage process. Figure 2 illustrates the manufacturers name and caliber on the side of the barrel and figure 3 illustrates a view of the muzzle with the original crown and the rifling impressions left by the button swage inside the original barrel.

The button swage rifling method involves forcing a tungsten carbide button with negative rifling impressions on the surface through the barrel under high pressure leaving very smooth rifling. Under extreme pressure, this button forms, rather then cuts, the rifling in the barrel. Consequently, the appearance of the inside surface shows none of the coaxial cutting marks associated with a broach[1] method.

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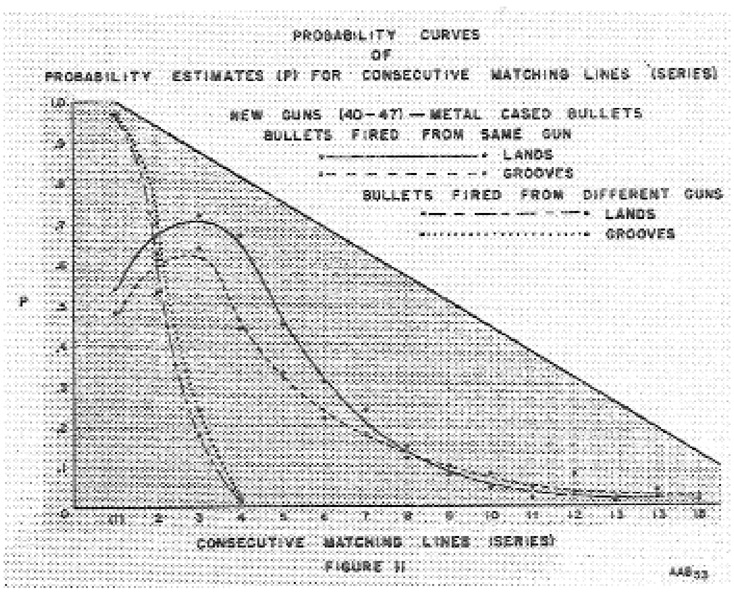

Figure 1 Probability curve from Biasotti's Original Thesis

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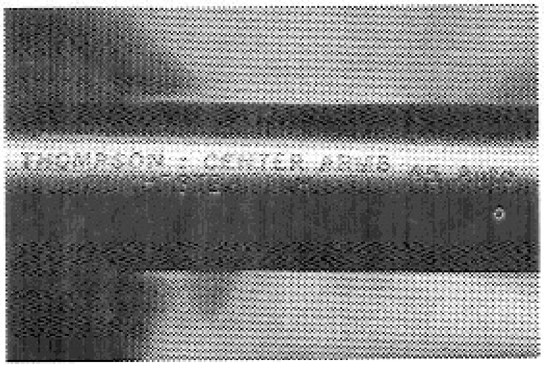

Figure 2. Thompson Barrel

Instead, what were usually visible were the remains of the circular reaming marks. This custom 15-inch long Thompson Center Arms barrel was chambered for the .45 ACP cartridge. The entire length of the bore was cast with Microsil[1] prior to any firing or machine cuts of the barrel. The details of the rifling impressions left in this silicon rubber cast media are illustrated in figure 4.

An index reference line was scribed along the longitudinal axis of the barrel at the 12 o'clock position. Six one-inch segments were marked out on the barrel and designated as section A, through G, with G remaining as part of the Thompson Contender barrel. The barrel was installed in a Thompson Center frame and six 45 ACP cartridges were fired through the uncut barrel. The first four bullets fired were used for conditioning[1] purposes. The bullets were test fired into and collected in a cotton box. All subsequent test firings were conducted with cartridges from the same ammunition box[2]. The cartridges and the bullets were indexed to the 12 o'clock reference position on the barrel. After each test firing, the barrel was taken to the machine shop and another section was removed. After section F was removed, the remaining barrel was test fired and the bullets labeled as G. The barrel was subsequently given a light crowning by a cutting tool, which had been given a slight bevel. Subsequent examination of the crowning showed a very slight bur at the end of each land and it is somewhat irregular in appearance and consistency. After this crowning, the barrel was again test fired. These test-fired bullets were labeled as H. Figure 5 illustrates the sectioning of the Thompson barrel.

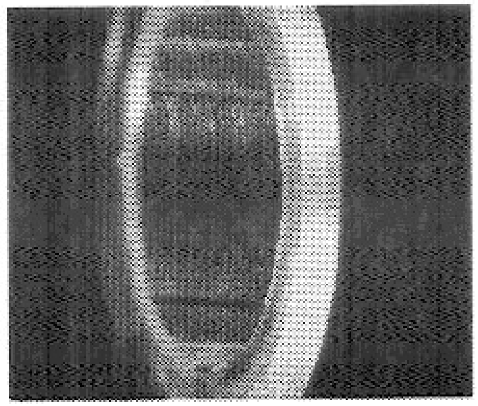

Figure 3. Original Crown

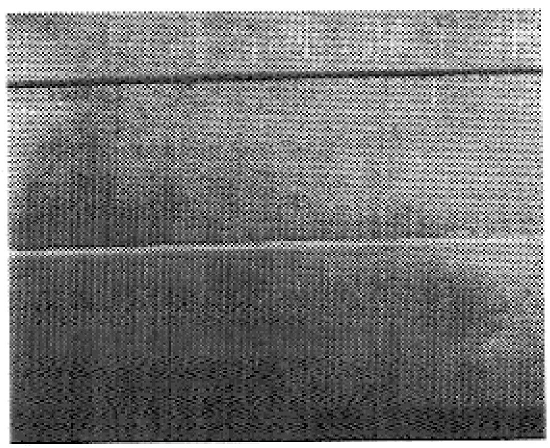

Figure 4. Microsil cast of the barrel (16X)

WIRE EDM PROCESS

A one-inch section at the muzzle end was cut off by the wire electron discharge machining process (EDM). The cutting process was done at the machine shop[1]. The procedure involved securing the barrel in a stationary position on the wire EDM machine. A brass wire does the cutting, typically 0.008 or 0.012 inches in diameter, as it is pulled across the metal to be cut. An electric current in the wire is adjusted and controlled by computer. The wire is on a continuous feed from a large spool and is only used one time for a machine operation. A continuous flow of deionized water over the machining operation flushes away debris as the wire removes metal

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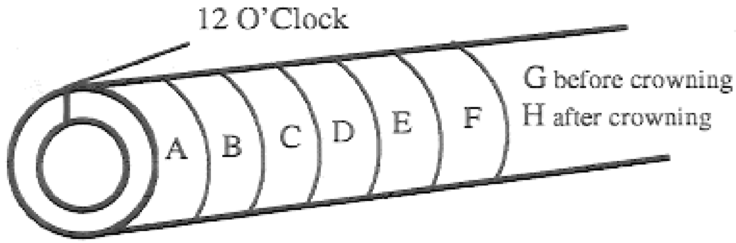

Figure 5

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during the cutting. Two additional passes were made with the wire to give a smooth, burr free finish. DC current of approximately 40 amps is used for the first rough-cut, leaving a finish of about 200 RMS[2]. The finish on the intermediate cut is around 80 RMS and the final finish cut was about 25-35 RMS. The wire can be moved with great accuracy, and precision in as small an increments as 10/1,000,000 inch. Four cartridges were test fired and collected after a section was cut. The steps in the wire EDM cut are illustrated in figures 6 to 10. Altogether, approximately .010 inch of actual metal was removed during this process.

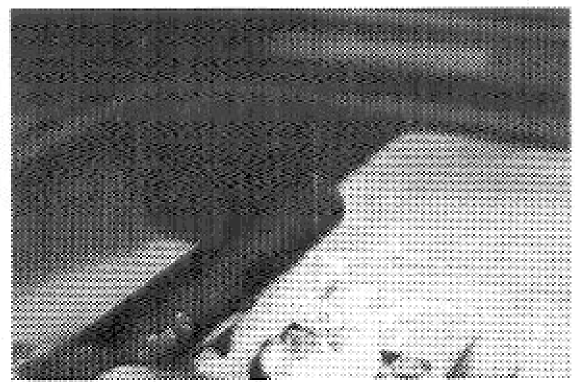

Figure 6. Wire EDM ready to cut

The cut ends of each section were observed by both the optical and in one case by scanning electron microscope for surface defects. Figures 11 and 12 illustrate views of the cut end of a new muzzle mark at 8X and 16 X respectively. Figures 13 and 14 illustrate the SEM images at 34X and 50X of these ends. It was quite apparent that the wire EDM process left no burr or other defects that could mark the surface of the test bullets as they passed by the cut. The most prominent features observed inside the barrel sections adjacent to the cut muzzle were the original reaming marks.

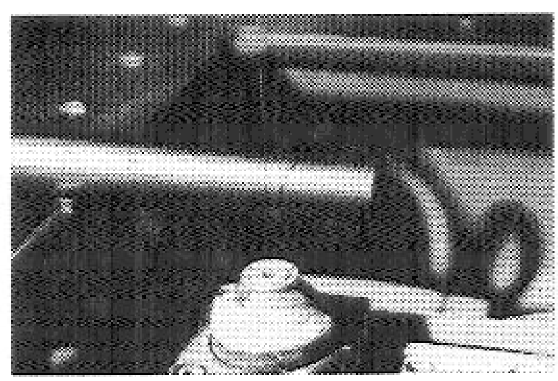

Figure 7. Wire EDM ready to cut

TEST FIRING PROCEDURES

Before firing, each cartridge was scribed in the appropriate position to ensure that the bullet could be properly orientated and identified as having been fired at the twelve o'clock position. The land impression at the scribe mark was denoted as land impression one. The land and groove impressions were then numbered sequentially in a clockwise

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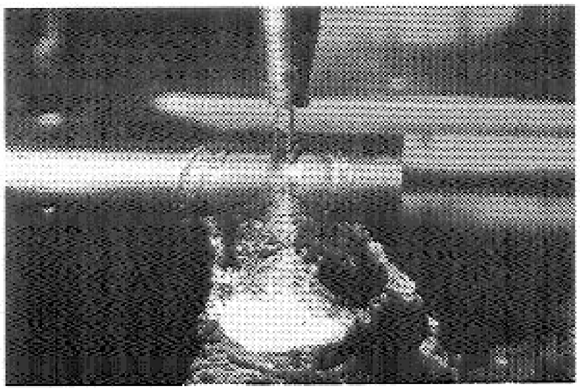

Figure 8. Deionized water on Wire EDM during the Cut

Figure 9. Finish of EDM cut Deionized water turned off to show finish of cut

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direction around the bullet. The last two bullets of the first set of six test fired bullets (A5 & A6) were compared to each other. In subsequent test firing, four bullets were test fired with the first bullet used for conditioning and the remaining bullets for comparison. The last bullet test fired from a section was compared to the second bullet fired from the next barrel segment. All different barrel segment comparisons were made with the test bullet at the 12 O'clock index mark lined up, or phased. In this way, land impression one of bullet A6 was compared to land impression one of bullet B2, and so on.

Velocity measurements were conducted, but during the course of the testing protocol, the Chronograph began to fail and give erratic values. However, the indication was that the bullet velocity for the 15" uncut barrel was about 880 feet/sec while the velocity from section E appeared to be about 850 feet/sec.

After the bullets had been fired from section G, the barrel was given a light crown and the bullet series labeled H were fired following crowning. The actual sequence of comparison is illustrated in figure 15.

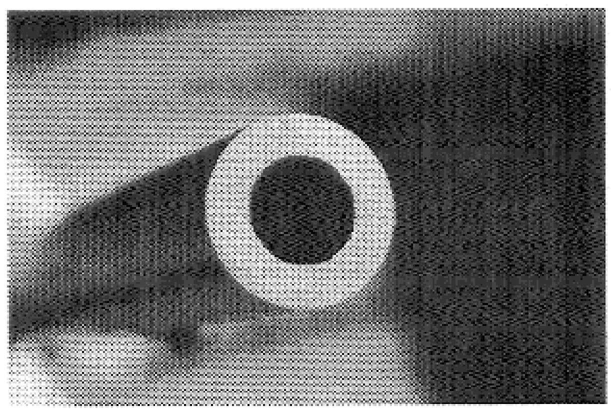

Figure 10. View of the surface

COMPARISON

The comparisons were made on a Reichert comparison microscope using a 10X ocular and a 4X objective, giving a measured magnification of 40X. The magnification was sufficient to allow full view of a land or groove impression. The bullets were held by a spring-loaded clamp, with the nose of the bullet placed in clay and the base set on a flat plate. A high intensity daylight fluorescent tube attached to each stage provided illumination. An aluminum reflector was placed opposite the light source to provide even lighting conditions. Each land/groove impression was

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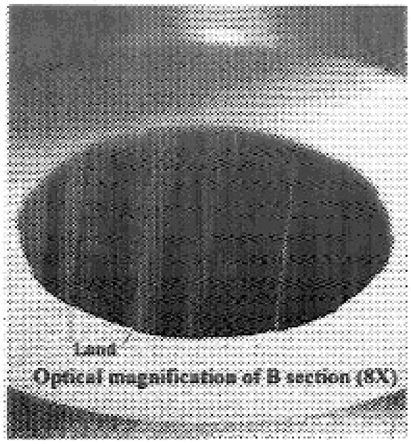

Figure 11. Magnification at 8X

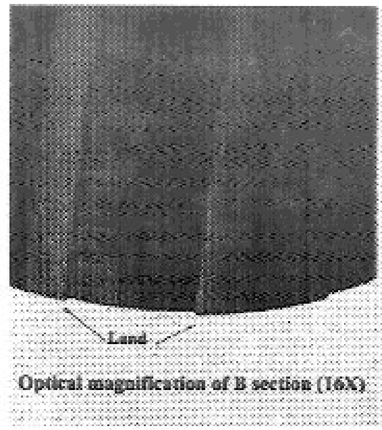

Figure 12. Optical magnification at 16 X

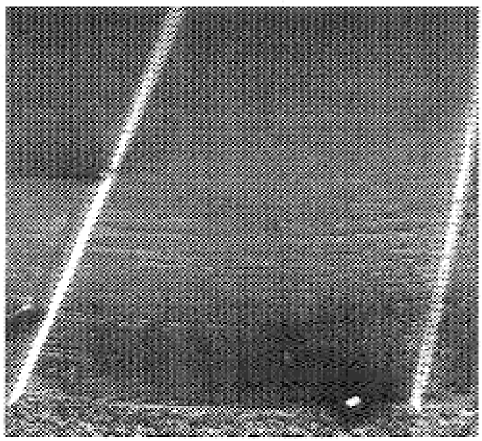

Figure 13 SEM image of land (34X)

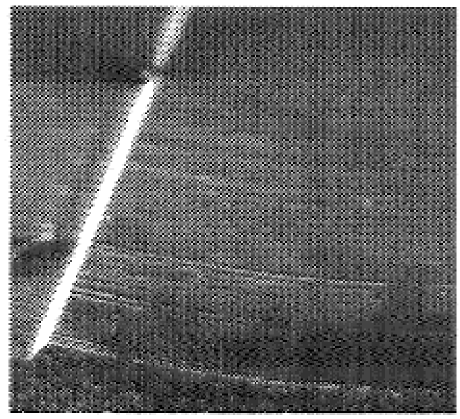

Figure 14. SEM image of land (50X)

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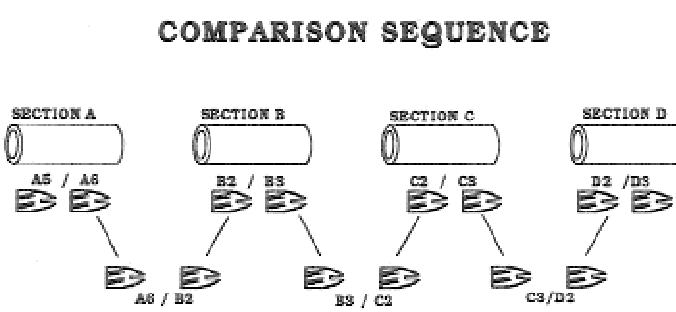

Figure 15. Comparison Sequence

compared with its corresponding in phase land/ groove impression. The total line count of each land and groove impression was recorded along with the number of singles, doubles, triplets, etc. that were found in each land or groove impression comparison. The counts were made with the aid of a particle counter. For example, when a "triple" was found the third key of the counter was depressed, while the person doing the comparison could keep their eyes focused on the impression. This facilitated the counting process. In order to facilitate inter-comparison, the particular area of the bullet that was used in the comparison was also recorded. This was done by dividing the land or groove impression into four equal segments designated A through D from the base toward the nose. The students compared each section and recorded data from the one that gave them the best match.

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DATA RECORDING

The data was recorded on a standard form (figure 16). The percent match and average line count were calculated and recorded on this sheet. This data was subsequently entered into an Excel spread sheet program for further data reduction and statistical analysis. The data was developed into frequency of consecutive matching striae for land impressions and groove impressions, probability estimates of matching striae, percentage of matching striae, variability between students, and regression analysis when appropriate using the statistical package that comes with Excel.

DATA RESULTS

The basic general rifling characteristics of the fired bullets and the number of striae in the Land/Groove impressions are described in Table 1

STUDENT LINE COUNT COMPARISON

The comparison of the consistency of consecutive line counts by each participant, for the bullets fired from different barrels sections, is illustrated in figures 17 and 18. These charts show that the different participants where very consistent in their counts. While differences do exist and are to be expected, what is significant is that the agreement between participants was fairly uniform as the striae counts exceeded 3 consecutive striae.

FREQUENCY DISTRIBUTION OF THE RAW DATA

The frequency distributions of the consecutive matching striae in the land and groove impressions from the comparison of bullets fired from adjacent sections in are illustrated in Figures 19 and 20.

The frequency distributions for the striae in Land and Groove Impressions comparisons from the same barrel sections are illustrated in Figures 21 and 22.

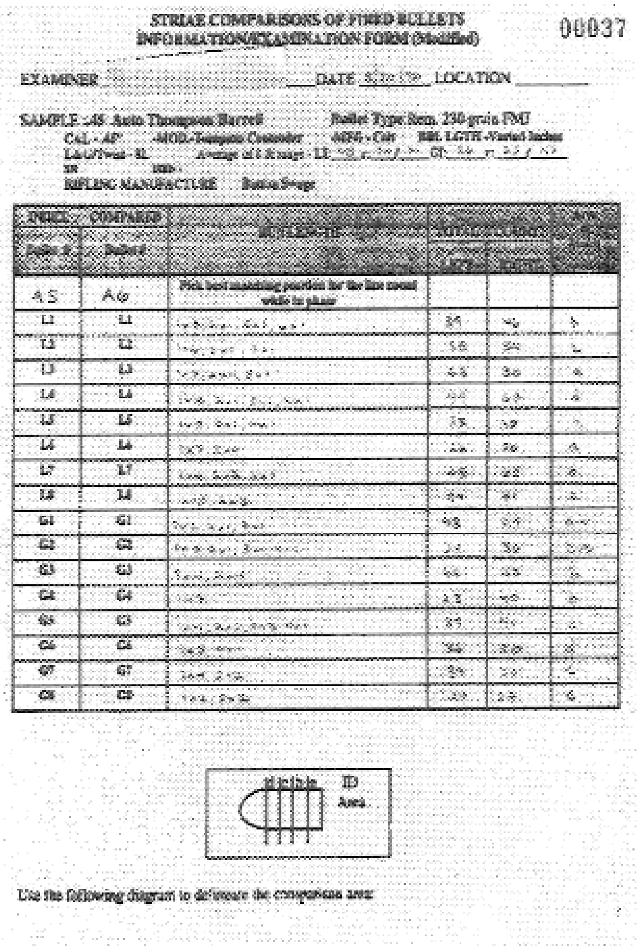

Figure 16. Student data sheet

The calculated exponential slope or trend line for the curves associated with this frequency data is tabulated in Table 3 taking the form:

$$y = ke^{-ax}$$

In performing this calculation, the equation does not allow for any zero values for number of consecutive striae, thus in order to perform the exponential curve calculation, a minor adjustment had to be made. This meant moving no more than one line count to a lower value in the striae observed in comparisons from the same section.

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NUMBER OF BULLET LAND AND GROOVE IMPRESSION COMPARED

There were eight bullets used for comparison and four students analyzed these bullets. The basic data from these observations is tabulated in Table 2.

Bullet Diameter	0.45"
Land and Groove Impression Twist	Left
Number of Land and Groove Impressions	8
Twist rate	1 Turn in 13"
Land Impression Width	0.083"
Range	0.082"-0.084"
Groove Impression Width	0.087"
Range	0.086"-0.088"
Average number of Striae per Land Impression	66
Standard Deviation	7.9
Average number of Striae per Groove Impression	38
Standard Deviation	6.9

Table 1

NUMBER OF BULLET LAND AND GROOVE IMPRESSIONS COMPARED

Number of Bullets	8
Number of Land Impressions (LI)	64
Number of Groove Impressions (GI)	64
Number of land plus groove impressions per set of two Bullets	128
Number of LIs' actually compared by students (Same section and different sections)	464
Number of GIs' actually compared by students (Same section and different sections)	464

Table 2

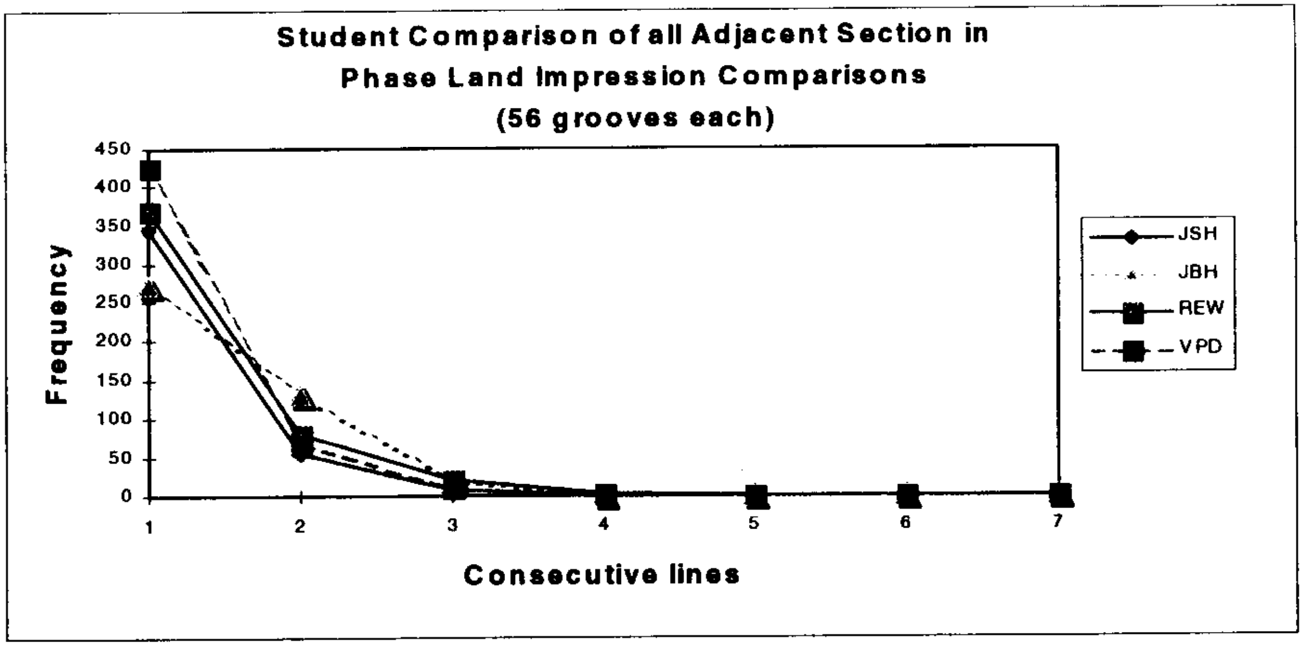

Figure 17. Student comparison for adjacent section land impression comparisons

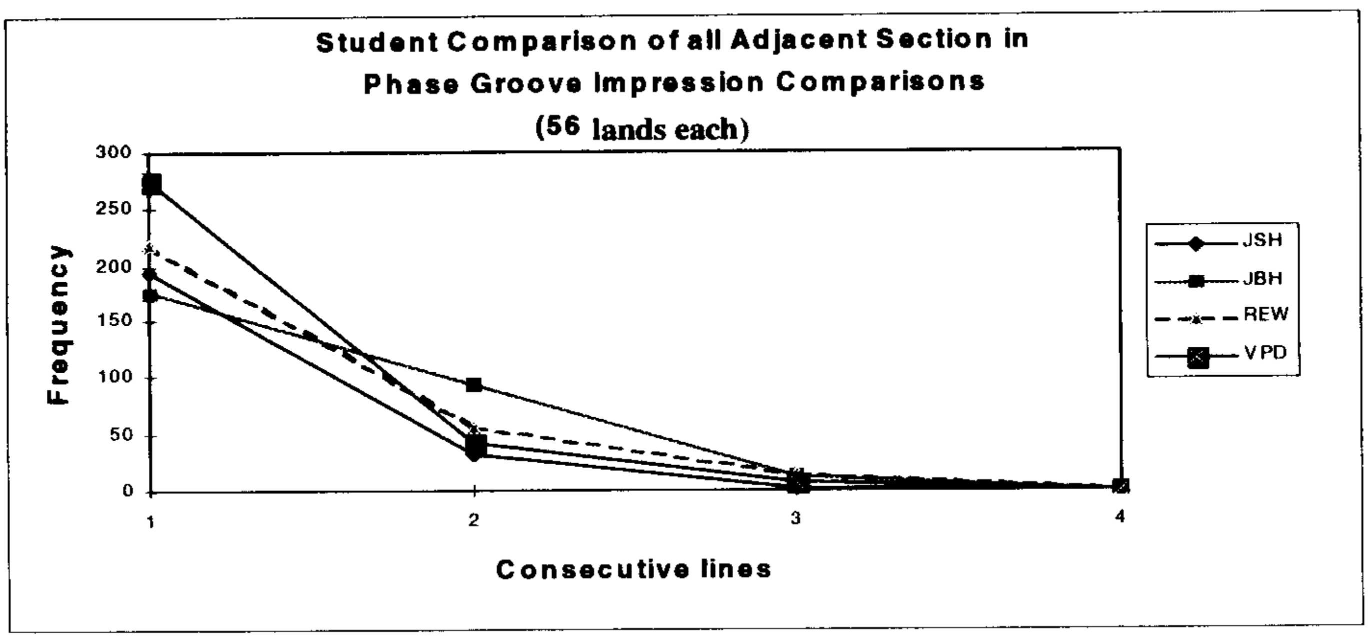

Figure 18. Student comparison for adjacent section groove impressions comparisons

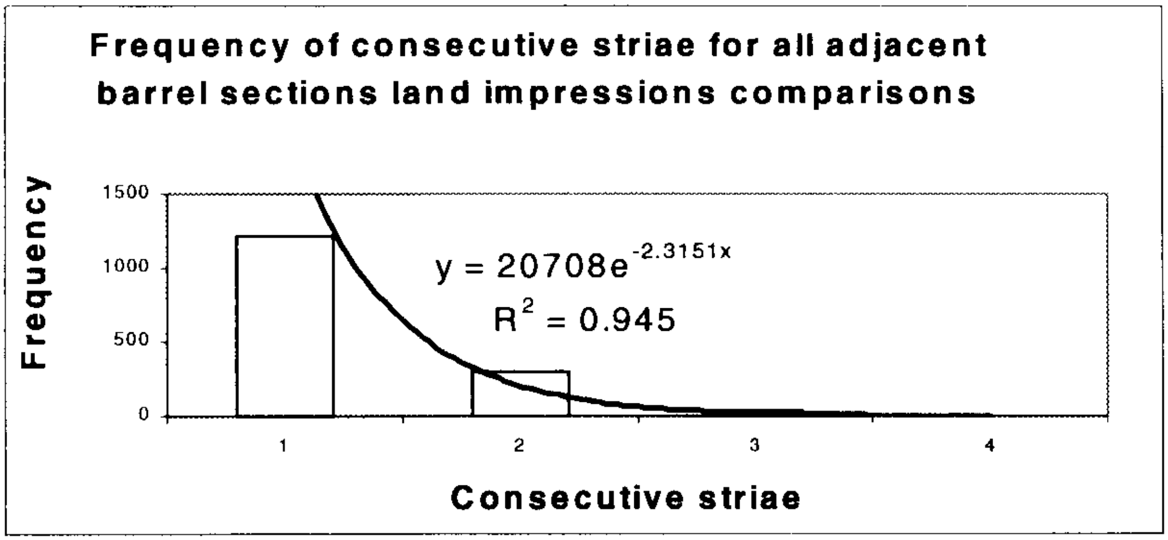

Figure 19. Frequency distribution of striae in land impressions from adjacent barrel sections

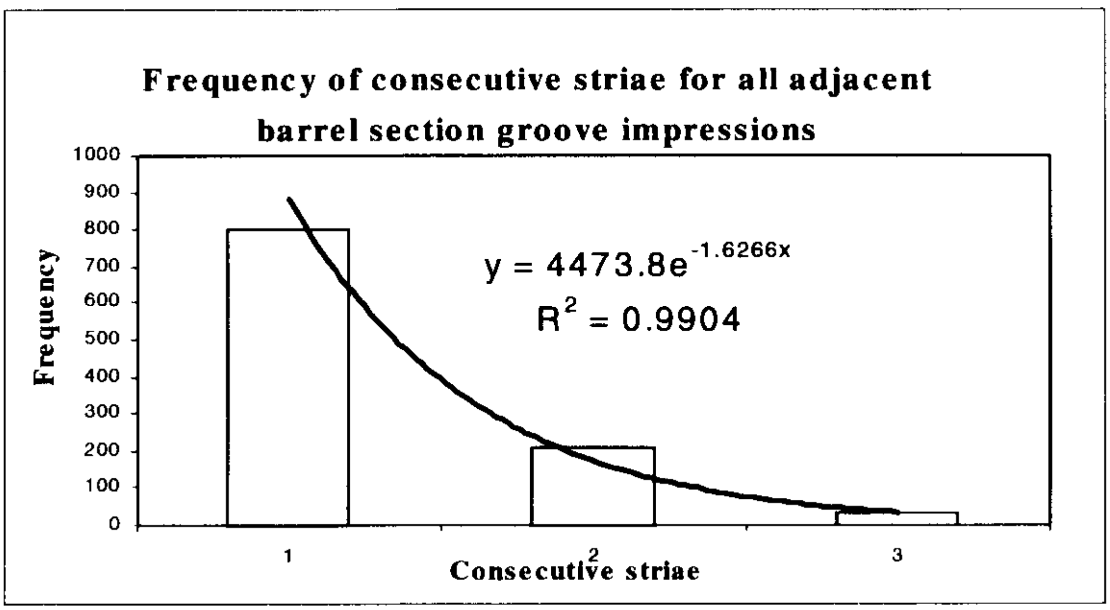

Figure 20. Frequency distribution of striae in groove impressions from adjacent barrel sections

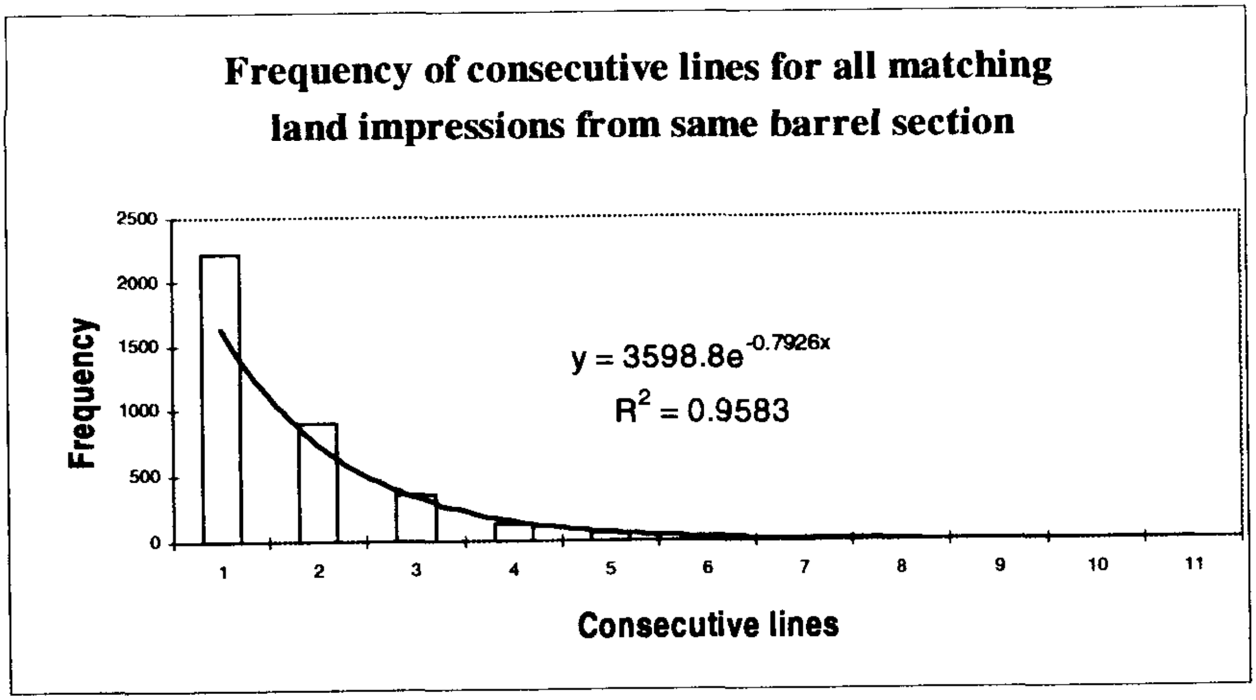

Figure 21. Frequency of consecutive striae for all matching land impressions

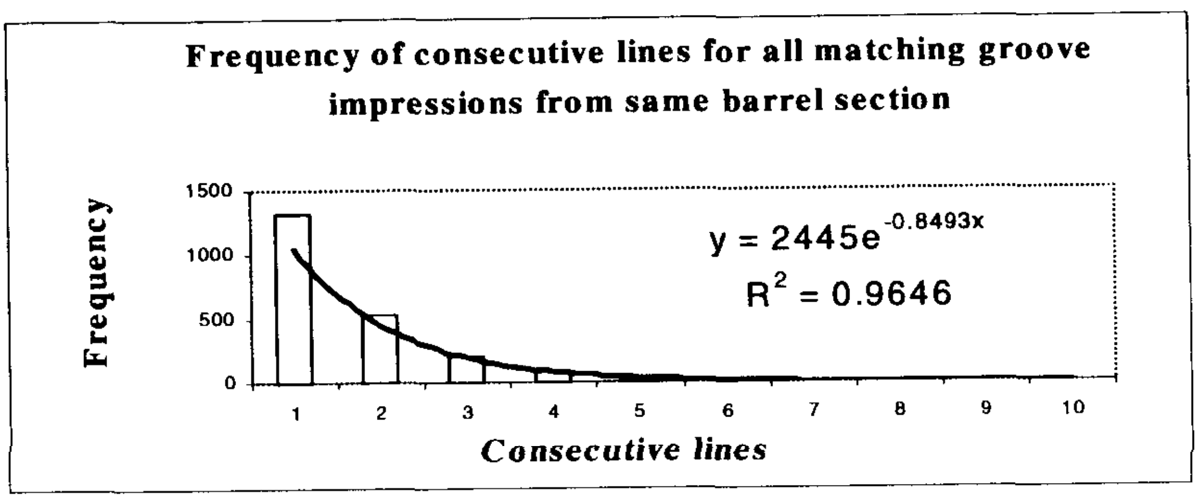

Figure 22. Frequency of consecutive striae for all matching groove impressions

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Thus a striae count of six was lowered to five. This does not affect the final result or influence the overall equation. The modified transformed regression model for these calculations is given by:

$$R^2 = \frac{\Sigma(y - y)^2}{(\Sigma y^2) - \frac{(\Sigma y)^2}{\eta}}$$

PROBABILITY ANALYSIS

In his study, Biasotti described an equation for calculating probability estimates from the frequency of occurrence for "runs" of matching striae. The probability estimates for the present study were calculated using the formula from Biasotti's[1] thesis. In this formula, the probability of finding one or more events (single, double, etc.) is calculated by dividing the number of land or groove impressions containing one or more events by the total number of compared land or groove impressions . For example in this study 464 land impressions were compared. Assume 464 of these impressions had at least one single matching striae, 232 had at least one double (2X), and 116 had at least one triple (3X). The probability estimate for "singles" would be 464/464 = 1.0, the estimate for "doubles would be 232/464 = 0.50, and the estimate for "triples" would be 116/464 = 0.25. The formula is as follows:

P= X/N where P= the probability estimate for a given series, X^1, X^2, X^3, ...n

X= The number of land or groove impressions containing one or more of the series

N= The total number of land or groove impressions giving total X.

Data Set	k	A	R^2	Fig.
Adjacent Cut Barrel Section Land Impressions	20708	2.315	.945	18
Adjacent Cut Barrel Section Groove Impressions	4473	1.6266	.990	19
Same Barrel Section Matching Land Impressions	3598	.793	.9583	20
Same Barrel Section Matching Groove Impressions	2445	.8493	.9646	21

Table 3

PERCENTAGE OF MATCHING STRIAE

While percentage of matching striae can be used to illustrate a degree of similarity, simple percentages do not provide an adequate description for identification purposes. A set of 10 consecutive matching striae is much more significant than a 30 or 50% striae match. In fact one could a have legitimate match with sufficient consecutive lines even if the overall per cent match is 15%. In fact, 12 consecutive matching striae out of 50 striae total is much more significant than the 24 single matching non consecutive striae out of a hypothetical 50 striae total. Regardless, for whatever it is worth, table 4 illustrated the total percentage match for all the observations in this study.

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Data Set	Percent Match %
Matching in phase Land Impressions striae from adjacent barrel sections	15.3
Matching in phase Groove Impressions striae from adjacent barrel sections	17.5
Matching in phase Land Impressions striae from the same barrel sections	34.5
Matching in phase Groove Impressions striae from the same barrel sections	33.8

Table 4

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This type of probability estimate was calculated for each comparison of adjacent barrel sections and then graphed for comparison. All land and groove impressions were also combined to give a larger sample size. Probability estimates were then calculated for the larger group to show the overall trend.

Probability estimates can also be calculated for two, three, or more events. This treatment would eliminate any land or groove impressions that had only one event occur, which would cause the probability estimates to be lower. This type of calculation was not performed in order to keep the probability estimates for known non-match comparisons as high as possible.

It appears that Biasotti used a method that would give the lowest probability to a consecutive line series. Thus, if a set of three matching striae were to appear on one land impression, it would still count for only one incident for that land impression. Another way to calculate probability is to add up the total number of observations of different consecutive line counts and then calculate the probability of each set of matching striae. One problem with this method is that as the number of consecutive matching striae increases, it will affect the count of matching lines with lower sequences. Thus, probability in such a case would not be independent.

For present study, we attempted to utilize the same probability calculations that were used by Biasotti in his pioneering study. The results for the probability of consecutive striae in land impressions from bullets fired from adjacent barrel sections are illustrated in figure 23 and likewise for the corresponding groove impressions in figure 24.

Likewise, the probability curves for all matching in phase land impressions for bullets from the same barrel sections is shown in figure 25, and for the corresponding in phase matching groove impressions in figure 26. The combination of all the probabilities for the in phase adjacent barrel and same barrel sections and groove impressions is illustrated in figure 27.

DISCUSSION

This study was designed to observe and test several areas: 1) using consecutive matching striae as a criteria of match, 2) the effect on the individuality of button rifling and the continuity of the rifling marks in a barrel, 3) the ability of different examiners to achieve similar counting statistics, and 4) the utility of Wire EDM cutting on the muzzle of a barrel. In most of these areas, definitive results have been obtained. It should also be mentioned that the striae left in the land and groove impressions by the rifling process were very fine. The button rifling method, by its

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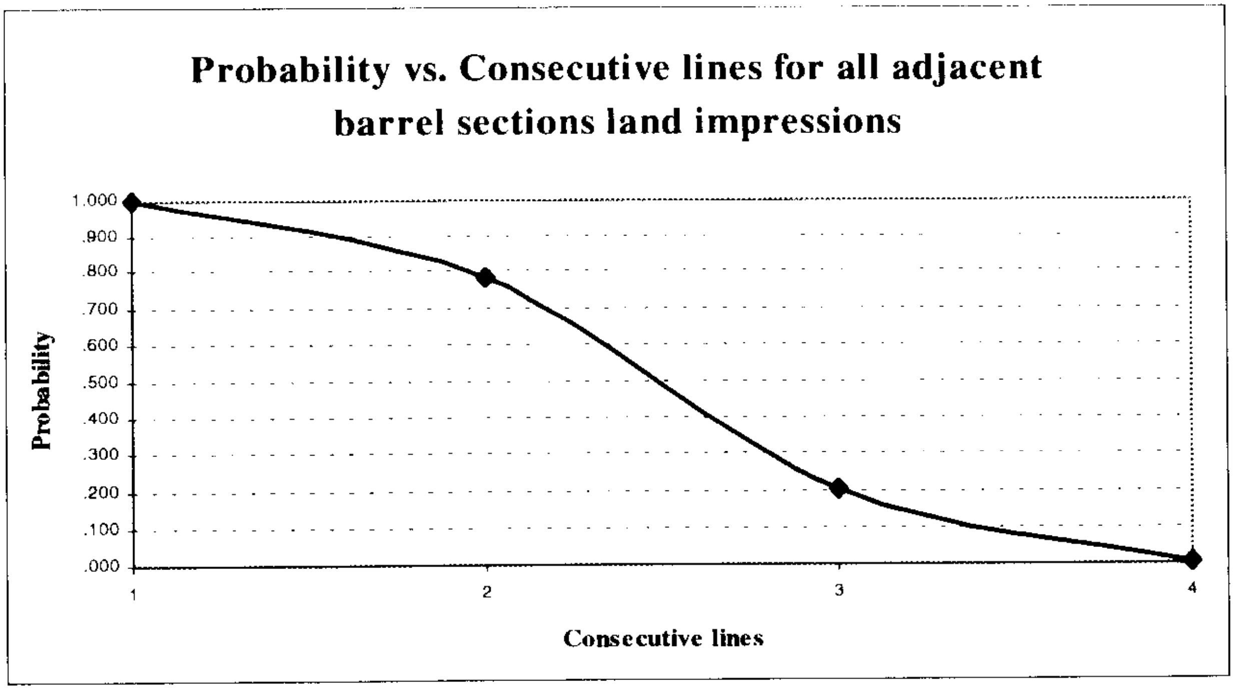

Figure 23. Probability of consecutive striae from adjacent barrel sections in phase land impressions

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very nature, leaves a very smooth surface. These bullets were not easy to match.

The Significance of Consecutive Matching Lines

The significance of consecutive matching lines first proposed by Biasotti[1] has not been repeated to any significant extent in published literature. But this concept has been used in classroom exercises[1] for the past 6 years with substantial success. In addition, several authors have contributed significantly to this area by postulating mathematical models. The first significant mathematical discussion was done by Bracket[2] who developed a one-dimensional model that was subsequently used as part of a class exercise in the Toolmark Criteria for Identification classes that have been held at CCI. Bracket predicted one dimensional exercise outcome with some succes. Uchiyama[3,4] and Deinet[5] have both presented extensive articles, which developed mathematical models. The present does not propose a model at this time. Instead, it attempts to validate previous observations by Biasiotti and confirm that his observations hold true for a different method of barrel manufacture.

The results illustrated by the frequency distribution shown in figures 18 and 19 show a very good regression fit for exponential decay when bullets from different barrel sections are inter-compared. With one exception, no more than three consecutive striae are observed when bullets from different barrel sections are inter-compared. The one exception is a set of six consecutive matching striae that appear to be axial in nature and originate from an area other than the barrel. When compared to bullets from the same barrel section, there are many more groups (figures 21 and 22) of consecutive matching striae exceeding three or more. The probabilities associated with finding these frequency profiles for the land or groove impressions are tabulated in figures 23 and 24 for in phase adjacent barrel section land and groove impressions and figure 25 and 26 for in phase matching land and groove impressions of the same barrel section. In an attempt to obtain some degree of independence for the probabilities, only one event per land or groove impression was included in the calculation of the probability, similar to the methodology in Biasotti's study.

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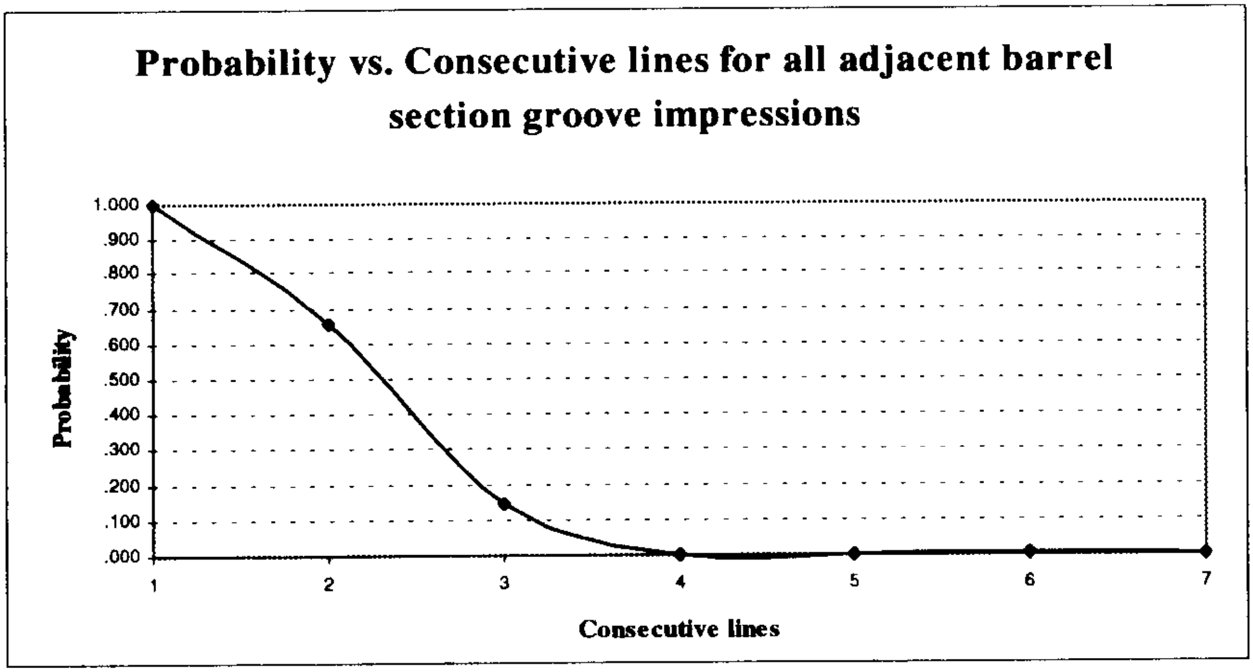

Figure 24. Probability of consecutive striae from adjacent barrel sections in phase groove impressions

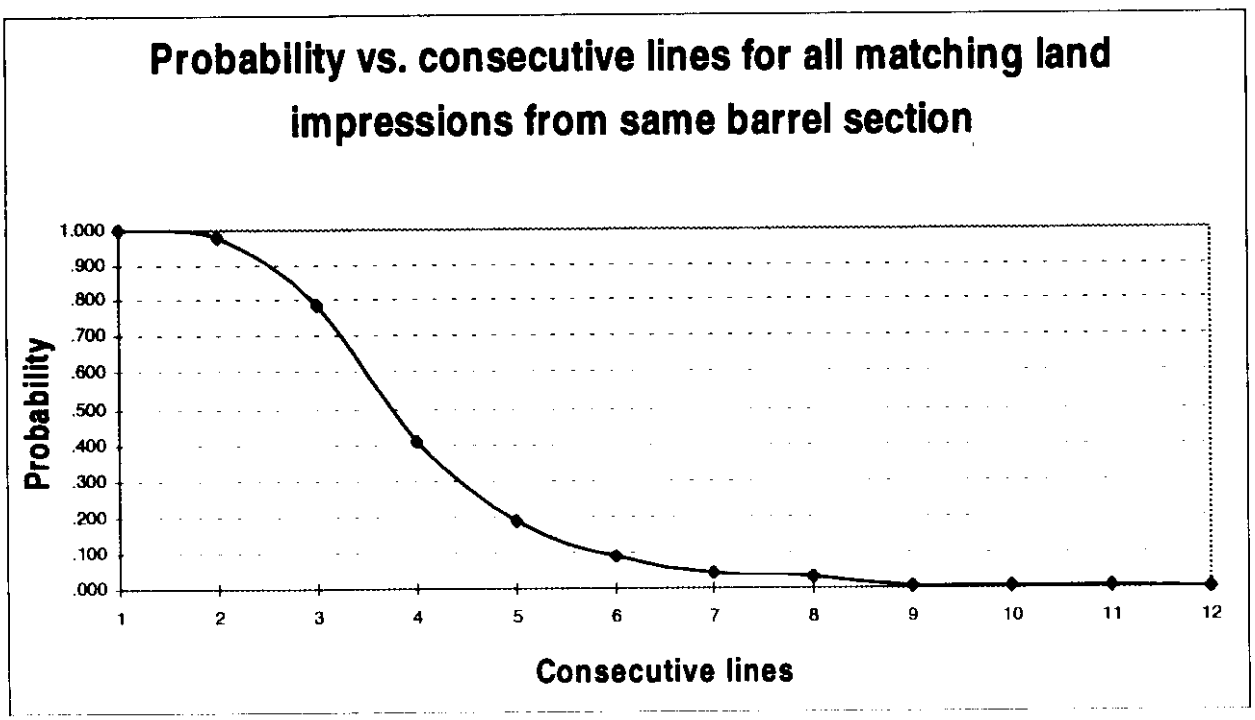

Figure 25. Probability of consecutive striae from the same barrel section in phase groove land impressions

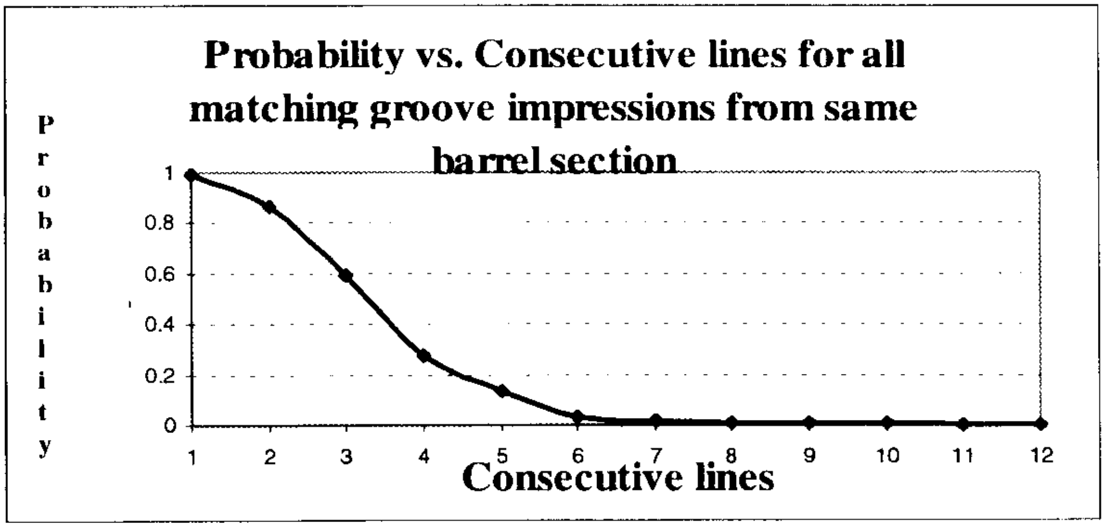

Figure 26. Probability of consecutive striae from the same barrel section in phase groove impressions

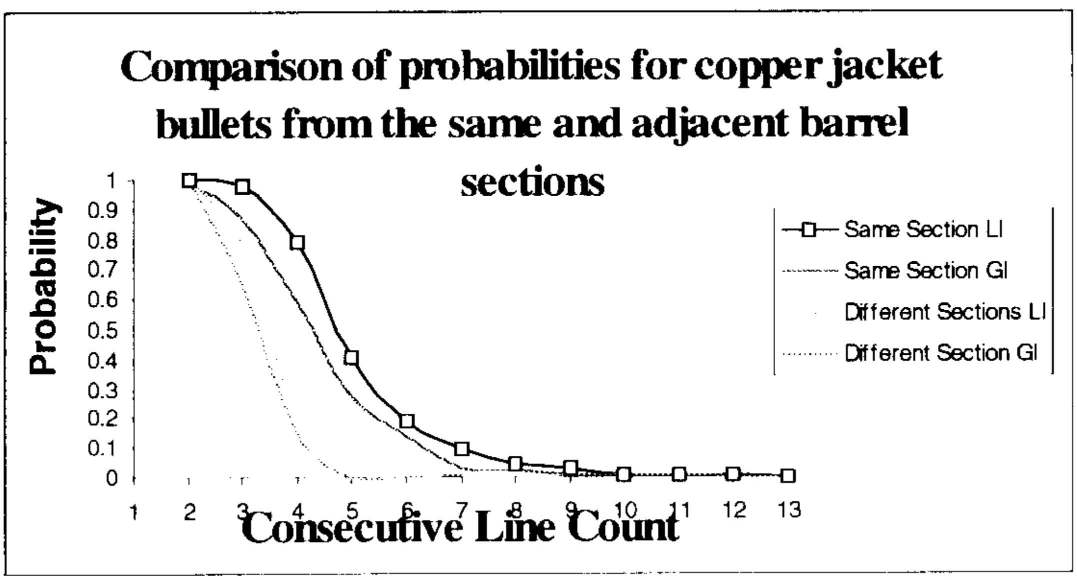

Figure 27. Combined probabilities for all land and groove impressions from the same barrel section and the adjacent in phased barrel sections

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While it's apparent that bullets from adjacent barrels sections give low consecutive matching striae counts, the consecutive striae pattern given by matching in phase bullets does not readily lend itself to a "significance score". As an example, a set of three consecutive matching lines in a tool mark are substantially less significant then a single set of nine consecutive matching lines. Uchiyama[6] did describe an algorithm used for his ALIS system that discounted any matching line count less than three. He performs a summary of the consecutive matching lines, subtracting a count of 2 from each set according to the formula Cns. No. = S (each consecutive run-2). According to him, this provides a powerful discriminator for matching bullets. This may very well be one form of an algorithm that can describe the degree of match. The question that naturally arises is; Will an exponential form of this algorithm provide a more realistic portrayal of the experimental results? At this time, this study will not attempt to formulate any such model.

The data generated in this study has the potential for subsequent analysis and evaluation with the current mathematical models. It is quite apparent that after three consecutive matching striae, one begins to move from the threshold of non-matching to a matching regime. The overall comparison of all this data is illustrated in figure 27.

The Significance of Rifling Change in a Button Swaged Barrel

The microscopic (optical and SEM) examinations do not show any rough surface left by the Wire EDM process. In fact, the most prominent feature in the lands and groove of the barrel are the original fine reaming marks left by the reaming tool prior to the button swage. Based on this, the assumption is that there will be significant microscopic changes to the rifling impressions imparted to test fired bullets when a short section of barrel is removed. This of course assumes normal manufacture with no gross carry over from defective rifling buttons or other tools prior to the final button swage operation. In the present study one-inch sections were removed, however it is quite possible that shorter sections would have sufficed. In fact studies[7] of rifled barrel manufacture by the metal removing step cutting broach method show that there is substantial change in the broach marks after one or two inches. Murdock[8] has also examined the issue of crowning versus no crowning. In his paper he finds that properly performed crowning does not affect the identification of the bullets fired from .22 caliber rifle barrels. Ideally the test bullets from section G (remaining barrel with no crown) and section H (remaining barrel with a slight crown) should show the same degree of correspondence to each other as they do to the bullets fired sequentially from the same section. In fact, there was sufficient correspondence for a match, however, there are differences as illustrated in figures 28 and 29. Further examination of the crowned surface of the barrel using a stereo microscope showed evidence of a slight burr left by the crowning procedure. This burr is most apparent at the end of each land and is somewhat irregular in appearance and consistency. The burr appears to be heaviest at the edges closest to the grooves. This was observed at an approximate magnification of 20X. It is still the belief of the authors that the Wire EDM did not leave any marks that would cause extraneous marks on the land /groove rifling impressions. This belief is predicated on the microscopic appearance of the cut sections.

Inter Comparison of Data Obtained by Independently by Different Observers

In this study, the inexperienced examiners did show some differences in what is perceived as single matching striae. This is illustrated in figures 17 and 18, however, the difference is substantially reduced when consecutive striae of two or more are counted. What is more significant is that while line counts may differ somewhat, the critical observation of consecutive matching striae generally not exceeding three for non known matching regimes is very consistent between examiners. These results are similar to what has been observed during classroom exercises held with experienced firearms examiners over the last six years at CCI and supports the findings of Biasotti and Murdock[3].

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(Continued on page 80)

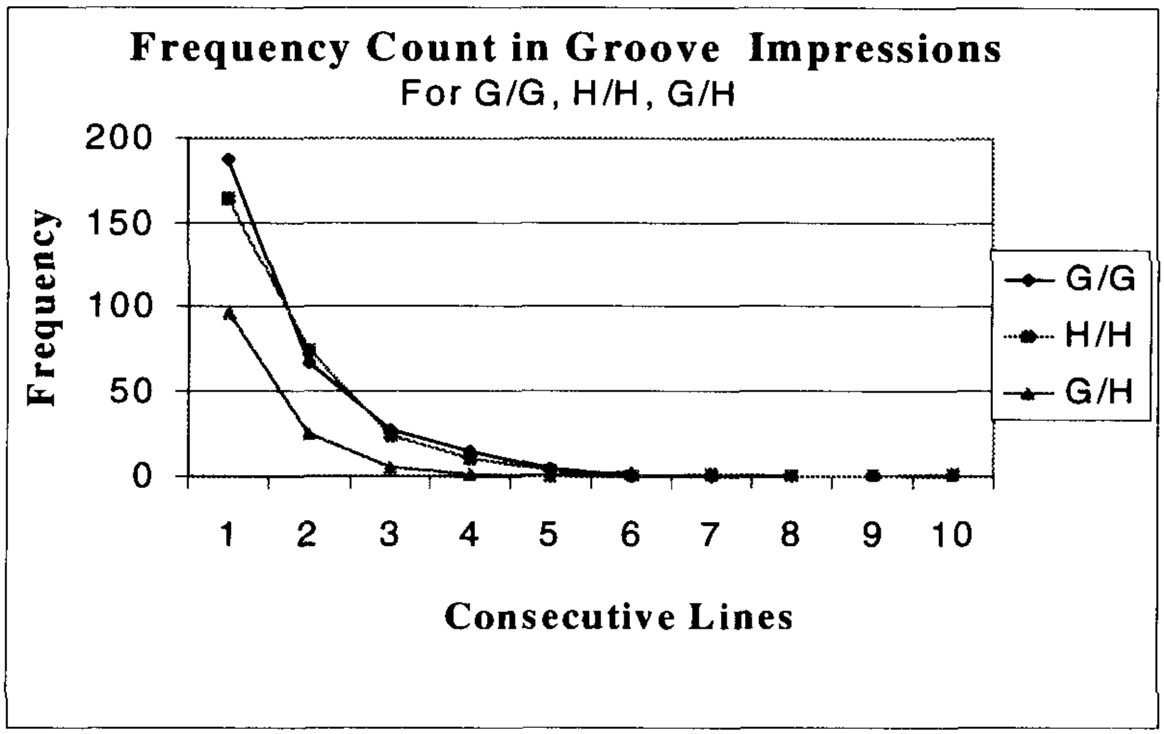

Figure 28. Frequency counts in land impressions for section

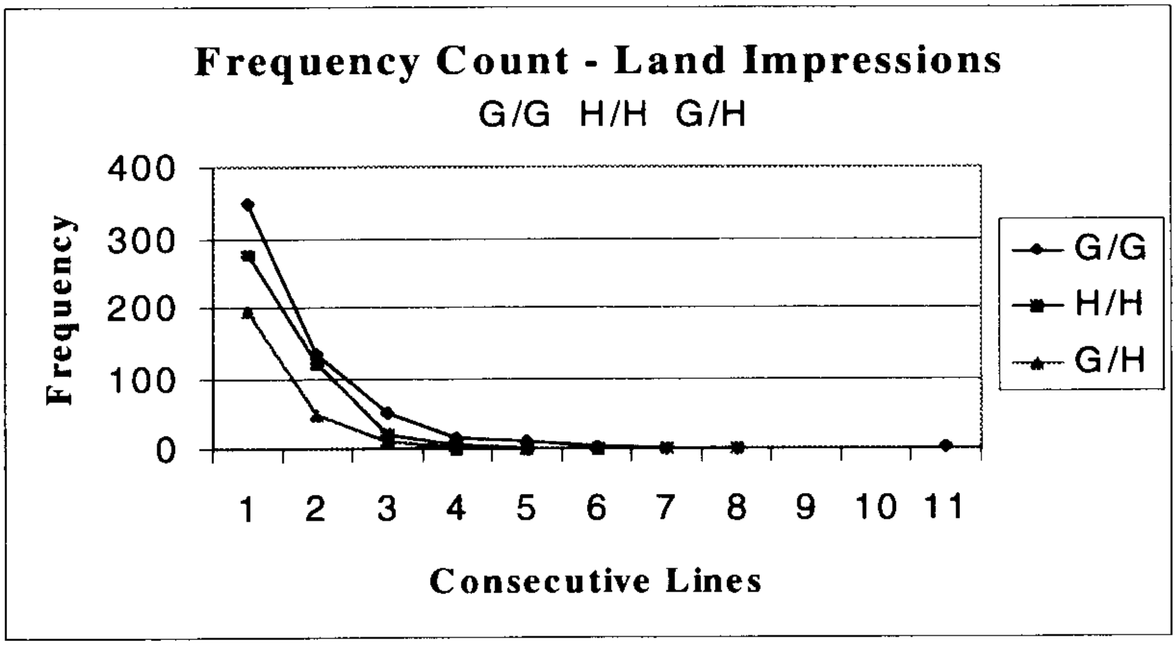

Figure 29. Frequency counts in groove impressions for section

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also validated with results obtained by experienced examiners and these results will be published at a later date.

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[1] Matching lines is a term used for brevity to denote matching striae either consecutive or non-consecutive which have a unique character, i.e. width, height, length and contour.

Percent matching lines denotes the percent of matching striae without regard to consecutive ness.

Consecutively matching lines are striae that cor respond or match with respect to each striae's width, depth and contour and are sufficient length to assure that striae are parallel to one another. The term striae is more commonly used than lines because the latter term is reserved for striae that are very shallow and thus appear virtually two dimensional "Biasotti A. & Murdock J. Firearms and Toolmark Identification Chapter 19, "The West Companion to Scientific Evidence August 1997, p30.

[2] Other studies

[3] Biasotti, Alfred A.: A Statistical Study of the In dividual Characteristics of Fired Bullets. J. of Forensic Science, Vol. 4, No. 1. January 1959.

[4] Broach method refers to a method of rifling wherein a series of broaches cut the rifling im pression in the barrel

[5] Mikrosil - A casting compound widely used for tool marks, made by Kjell Carlsson, Sweden

[6] Conditioning refers to the fact that with new barrels, several shots may need to be fired before the bullets generate reproducible striae.

[7] Remington .45 Auto FMJ 230 grain lot# H01YA4803

[8] Woodland Precision Technology, 1242 G Com merce Woodland, CA 95766, Greg Cook, Co-Owner.

[9] RMS, a measure of surface roughness.

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