Gear Code Extraction from Microstamped Cartridges

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ABSTRACT

The firing pins of three different handguns were modified to stamp a six-digit alpha-numeric code and a circumferential digital code known as a gear code into the primer of a cartridge when fired. In this paper the transfer of gear codes from firing pin to primers was evaluated using scanning electron microscopy (SEM). Only those cartridges that received poor clarity marks optically as regarding the alpha-numeric code were chosen for evaluation in the SEM. Photo editing software was employed to clearly outline and decipher the gear code around the circumference of the microstamped primer. Results show that the better imaging of the SEM allows more of the alpha-numeric identifiers to be distinguished as well as more of the gear code structure, however complete recognition is still not possible in all cases.

Introduction

Over the past few years, intentional firearm microstamping has received a large amount of attention from technical discussions [1-4], lawmakers [5], and the media [6-8]. Microstamping involves placing alpha-numeric identifiers onto the surface of various components associated with the firing of a firearm, such as the firing pin or breech face. These unique identifiers are then automatically transferred to the cartridge upon firing due to the forces involved in the action. While microstamping can be used to transfer large numbers of characters [9] more effort has been devoted toward an eight character alpha-numeric on the firing pin tip with a circular gear code around the circumference of the pin [2]. It is proposed that these microstamped identifiers can be used as a simple, objective, and rapid means of identification of a particular gun, similar to the way a license plate identifies a particular car. An example of a microstamped mark showing both alpha-numeric identifier and circular gear code is shown in **Figure 1**.

While simple visual observation can determine what the identifiers are if the microstamping is clear, distortion of the transfer makes their identification much more difficult. If the alpha-numeric characters are deformed, or partially removed due to the firing and cartridge ejection process, the only means of identification for the original microstamped identifier might be the gear code. Thus, the gear code could provide important information that could either fill in any gaps in a distorted

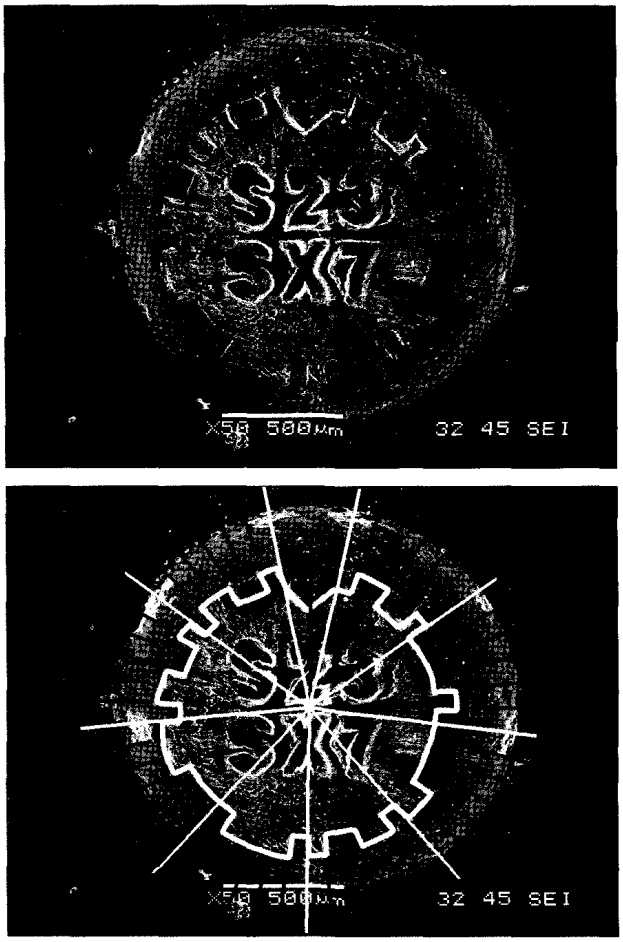

Figure 1: a) Microstamped mark from a Sig Sauer P226 semiautomatic handgun, top b) Microstamped mark with gear code overlay, bottom

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alpha-numeric code, or be used to replicate the code if the alpha-numeric identifier is entirely illegible.

The gear code is deciphered by dividing the circular code into eight equal sectors, excluding the wedge at the top of the gear code, which marks the start of the sequence (see gray line in **Figure 1b**). This translates to eight sectors of 42 degrees, delineated in Figure 1b by straight, white lines. The code is then read clockwise, in six bit binary, where each bit is a 7 degree increment, as shown in **Figure 1b** by black lines. The numbers "0" and "1" then correspond to whether the primer is left in the unstamped or stamped condition, respectively. For example, the first section of gear code in Figure 1b is then read as 011001, which corresponds to the letter "S" and is also the first character in the alpha-numeric code. The subsequent sectors correspond to the identifiers being read left to right. Thus, in **Figure 1**, the second sector represents the second character, 2, the third 3, etc. The gear codes contain the numbers 0-9 and all letters of the alphabet, excluding I, O and Q to eliminate any confusion in evaluation. More information regarding gear codes, microstamping, and translation of the digital code into the alpha-numerics can be found in the literature [2]. A table showing the digital code and the corresponding alpha numeric is shown in **Table I**.

In this study the efficiency of transfer of gear codes from micro-etched firing pins to a variety of ammunition types is reported. This paper constitutes a follow-up to an earlier study where the alpha-numeric was examined [3]. Readers are encouraged to consult this earlier study for a full understanding of the experimental design.

Experimental

Samples examined in this paper were described in a previous study [3]. Briefly, cartridges were fired and examined using three different semiautomatic handguns: a Sig Sauer model P226 pistol, a Taurus model PT609 and a Hi-Point model C9. Six character microstamped firing pins were optimized for these guns and ten different brands of ammunition representing a range of primer hardness and types were selected. Each gun was used to fire 100 rounds of each brand of ammunition, 10 rounds per magazine, for a total of 1000 rounds per firearm. The brands of ammunition used can be found in **Table II**.

Evaluation of the microstamped alpha-numeric identifiers has already been published [3]. Optical grades were given based upon the number of clearly legible alpha-numeric characters visible using a stereomicroscope. If all six identifiers were clearly read, the cartridge received a grade of C6, if only five identifiers were clear, the cartridge was graded C5, etc. For the current study, only fired cartridges that received an optical grade of C2 or below were chosen for evaluation for the Hi-Point. Since the Taurus and Sig Sauer generally received better optical grades, cartridges of less than C6 were evaluated. A total of 26 cartridges of poor grades were evaluated, seven from the Sig Sauer gun, seven from the Taurus, and 12 from the Hi-Point.

The selected cartridges were cleaned and examined using a JEOL 6060LV scanning electron microscope (SEM). Pictures were taken using either secondary electron imaging or backscattered electron imaging, depending on which imaging technique made the gear code more legible. The SEM images obtained were then examined using a free photo editing software (GIMP), the outline of clear gear code was traced, and an overlay of the correct angles was placed upon the image to evaluate the gear code.

Results

As with the previous microstamp study [3], the Sig Sauer had the best transfer of gear code and legible identifiers, while the Hi-Point and the Taurus did not transfer identifiers and gear codes quite as well. In this section examples of analyses from several selected cartridges will be presented, followed by a summary of results for all of the cartridges examined.

Sig Sauer

In **Figure 2**, Sig Sauer cartridge number 24 (Brown Bear) graded C2 optically is shown. More detail is visible in the SEM image than when using a stereomicroscope and the identifier appears to be S23-SX7 by simple SEM examination without resorting to the gear code. In this instance the gear code is complete and can be clearly deciphered. All eight characters are visible and decode as S23-SX7-SS, which confirms the assessment of the alpha-numeric based solely on SEM imaging.

While generally the Sig Sauer had the best and most consistent transfer [3], this was not true in all cases. **Figure 3**, shows an example of a poorly marked cartridge (Cor-Bon) that was graded C0 optically. The SEM image reveals more identifiers in addition to a partial gear code.

Estimating exactly how many of the alpha-numerics can be deciphered using SEM is somewhat artificial since the identifier is already known. While it is difficult to be totally objective, it would appear that an unbiased observer might make a reasonable guess at 2-3 of the alpha-numerics, possibly S*3 – S*7 at best, based solely on SEM imaging. While only part of the gear code can be deciphered, it still yields enough information to confirm the first three identifiers and part of

Value	Code	Dig1	Dig2	Dig3	Dig4	Dig5	Dig6	Concatenate
0	0	0	0	0	0	0	0	000000
1	1	0	0	0	0	0	1	000001
2	2	0	0	0	0	1	0	000010
3	3	0	0	0	0	1	1	000011
4	4	0	0	0	1	0	0	000100
5	5	0	0	0	1	0	1	000101
6	6	0	0	0	1	1	0	000110
7	7	0	0	0	1	1	1	000111
8	8	0	0	1	0	0	0	001000
9	9	0	0	1	0	0	1	001001
A	10	0	0	1	0	1	0	001010
B	11	0	0	1	0	1	1	001011
C	12	0	0	1	1	0	0	001100
D	13	0	0	1	1	0	1	001101
E	14	0	0	1	1	1	0	001110
F	15	0	0	1	1	1	1	001111
G	16	0	1	0	0	0	0	010000
H	17	0	1	0	0	0	1	010001
I		0						
J	18	0	1	0	0	1	0	010010
K	19	0	1	0	0	1	1	010011
L	20	0	1	0	1	0	0	010100
M	21	0	1	0	1	0	1	010101
N	22	0	1	0	1	1	0	010110
O								
P	23	0	1	0	1	1	1	010111
Q								
R	24	0	1	1	0	0	0	011000
S	25	0	1	1	0	0	1	011001
T	26	0	1	1	0	1	0	011010
U	27	0	1	1	0	1	1	011011
V	28	0	1	1	1	0	0	011100
W	29	0	1	1	1	0	1	011101
X	30	0	1	1	1	1	0	011110
Y	31	0	1	1	1	1	1	011111
Z	32	1	0	0	0	0	0	100000

Table I: Variable pitch gear code table

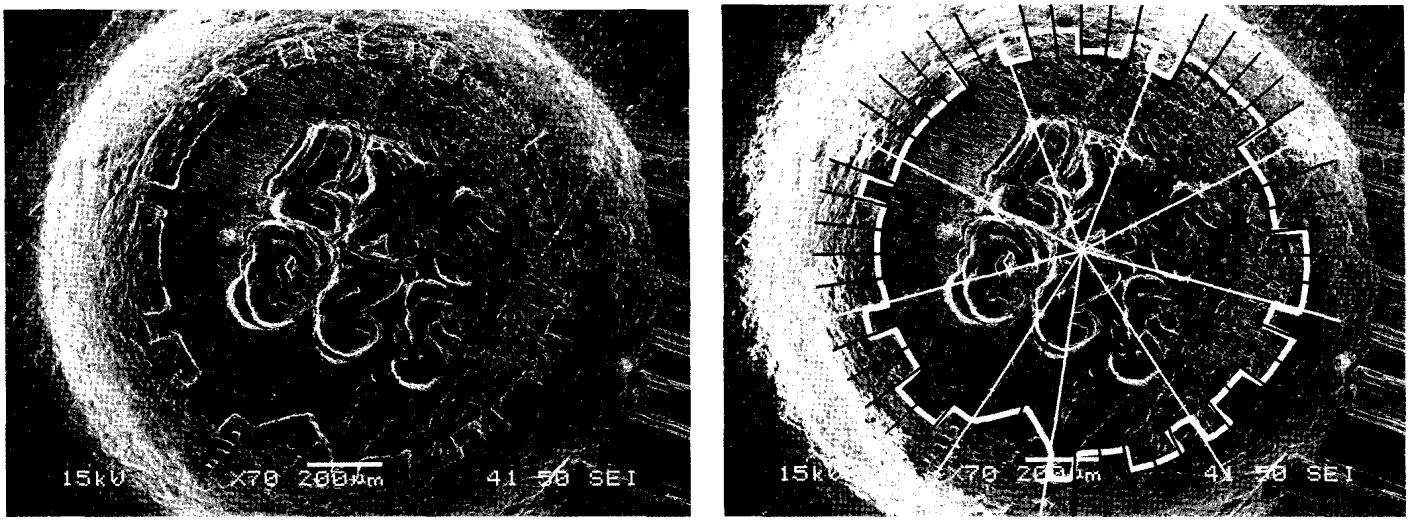

Figure 2: SEM image of a) Sig cartridge #24, Brown Bear, left b) Outlined gear code and overlay, right

Firing Order	Ammunition Brand	Primer Type	Primer Material	Description
1	Brown Bear	Berdan	Brass	115 gr., full metal jacket
2	DAG	Boxer	Brass	124 gr., full metal jacket
3	Federal - American Eagle	Boxer	Nickel	115 gr., full metal jacket
4	Remington - UMC	Boxer	Nickel	115 gr., Flat Nose Enclosed Base, letters "H F" stamped into the primer
5	PMC	Boxer	Brass	115 gr., full metal jacket
6	Silver Bear	Berdan	Brass	115 gr., full metal jacket
7	CCI Blazer	Boxer	Nickel	115 gr., full metal jacket
8	Cor-Bon	Boxer	Nickel	147 gr., full metal jacket
9	Independence	Boxer	Nickel	115 gr., full metal jacket
10	Sellier & Bellot	Boxer	Brass	115 gr., full metal jacket, primer covered with red lacquer sealant

Table II: Ammunition brands used in the study

the fourth. The first sector can be read as "S", the second as "2", the third as "3". Complete transfer fails at the fourth identifier.

Taurus

The Taurus firing pin did not mark gear codes nearly as well as that of the Sig. This was partly due to the sharper radius of the pin [3] and partly due to the sparse gear code on the pin [3], i.e. the code consisted of large continuous areas of stamped "1" or unstamped "0". This absence of surface relief was found to make it difficult to determine whether the cartridge was left unstamped to denote a 0 or whether the cartridge simply was not marked at all. As a result, very little additional knowledge as to the unique identifier was added by the presence of the gear code. An example is shown in **Figure 4**, which is cartridge, number 233 (American Eagle). Optically, this cartridge was graded C2, although the better imaging available using the SEM allows the first three alpha-numerics to be read as T13 fairly easily, with suggestions of 2 additional identifiers, possibly a 5 or an S, and a 1. When examining the gear code the sectors for identifiers 3-8 are not visible at all; the first two sectors of the code yield the correct identifiers T and 1.

In general for the Taurus cartridges examined, only the first two identifiers could be extracted from the gear code. **Figure**

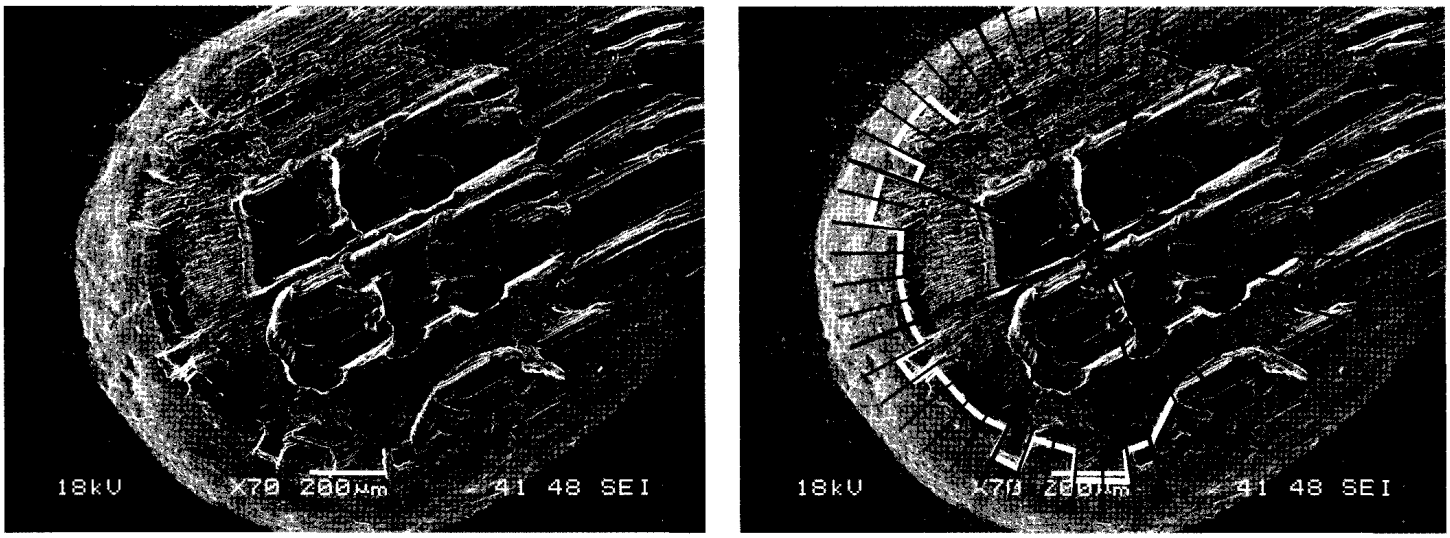

Figure 3: a) SEM image of Sig cartridge #707, Cor-Bon, left b) Outlined gear code and overlay, right

5 shows an even poorer alpha-numeric and gear code transfer from cartridge #296 (American Eagle) graded C1 optically. Again the SEM imaging allows 1 and 3 to be ascertained from the alpha-numeric but only the number "1" is able to be deciphered using the gear code, which falls in the second sector of the eight possible sections. All other sectors appear distorted, precluding any interpretation with a high level of confidence.

Hi-Point

Like the Taurus, the Hi-Point did not transfer its gear code as

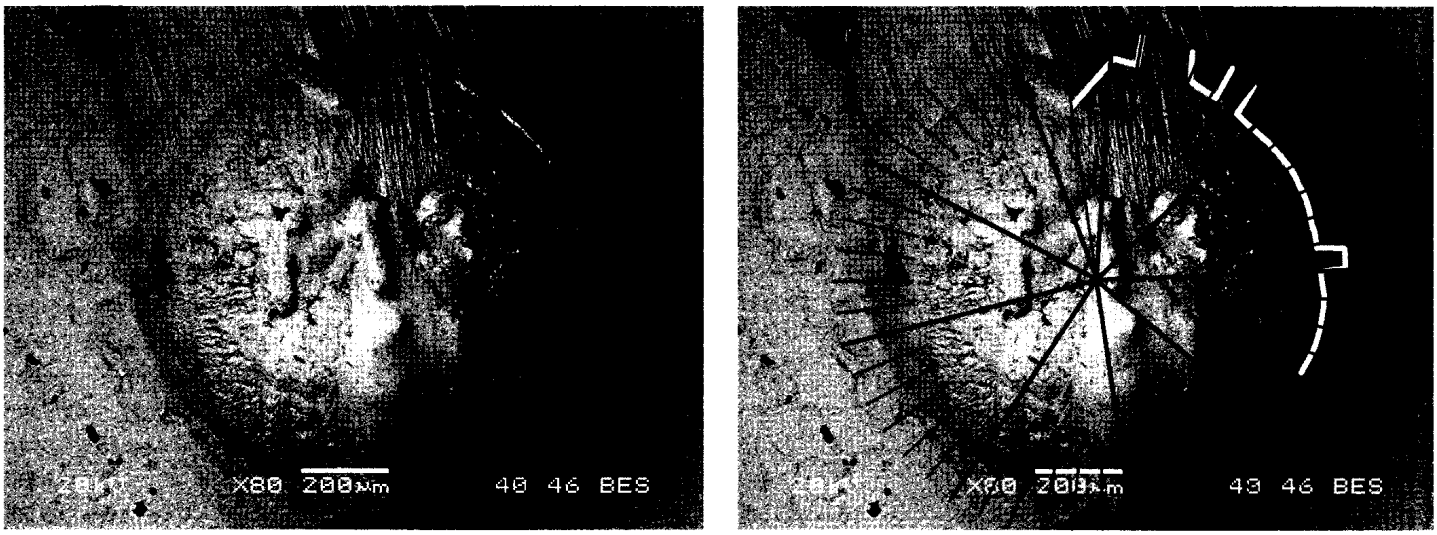

Figure 4: a) SEM image of Taurus cartridge #233, American Eagle, left b) Outlined gear code and overlay, right

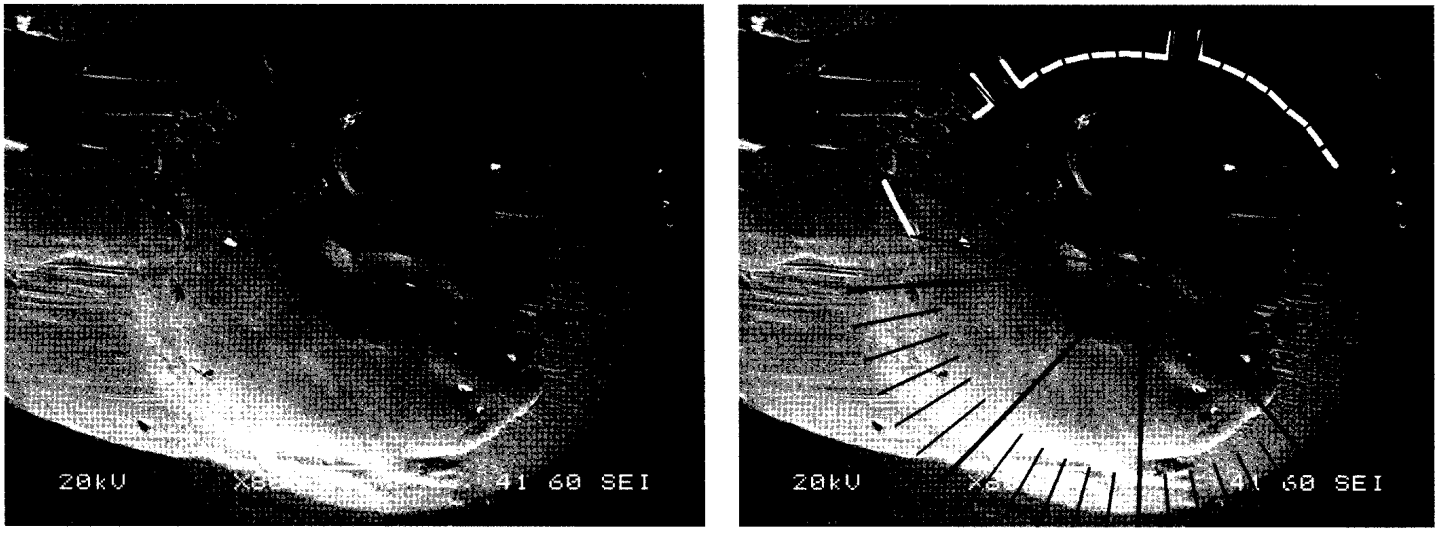

Figure 5: a) SEM image of Taurus cartridge #296, American Eagle, left b) Outlined gear code and overlay, right

well as the Sig Sauer. However, the Hi-Point pin did have a more robust gear code with considerable surface relief, which made it somewhat easier to discern if the primer had indeed been marked. In **Figure 6**, cartridge #610 (CCI Blazer) graded optically as C1 is shown. Again the SEM reveals more of the alpha-numeric than could be seen optically as well as a fraction of the gear code. In Figure 6a the identifier appears to be H60-PZ*, with the last alpha-numeric undistinguishable. When considering the gear code, "H" can be read clearly, but the "6" is slightly muddled. As the outline shows in Figure 6b, the gear code for the second identifier appears to read 000100, which would correspond to the number "4". This is obviously incorrect and forces an examiner to decide between what appears to be a clear marking of the alpha-numeric and the validity of the gear code.

In this particular cartridge, the primer seems to have been struck twice and smeared, which distorts the alpha-numerics and obscures the correct gear code reading of (000110). Double strikes were especially prevalent in the Hi-Point.

A second example is shown in **Figure 7**. This Silver Bear cartridge, #520, was graded C0 optically. However, when imaged with SEM reasonable guesses could be made as to the identity of most of the alpha-numerics. Although there is considerable uncertainty and judgment involved, the identifier seems to be an H or an A, followed possibly by a 6, then 0. The second three-digit sequence appears to be possibly a P,

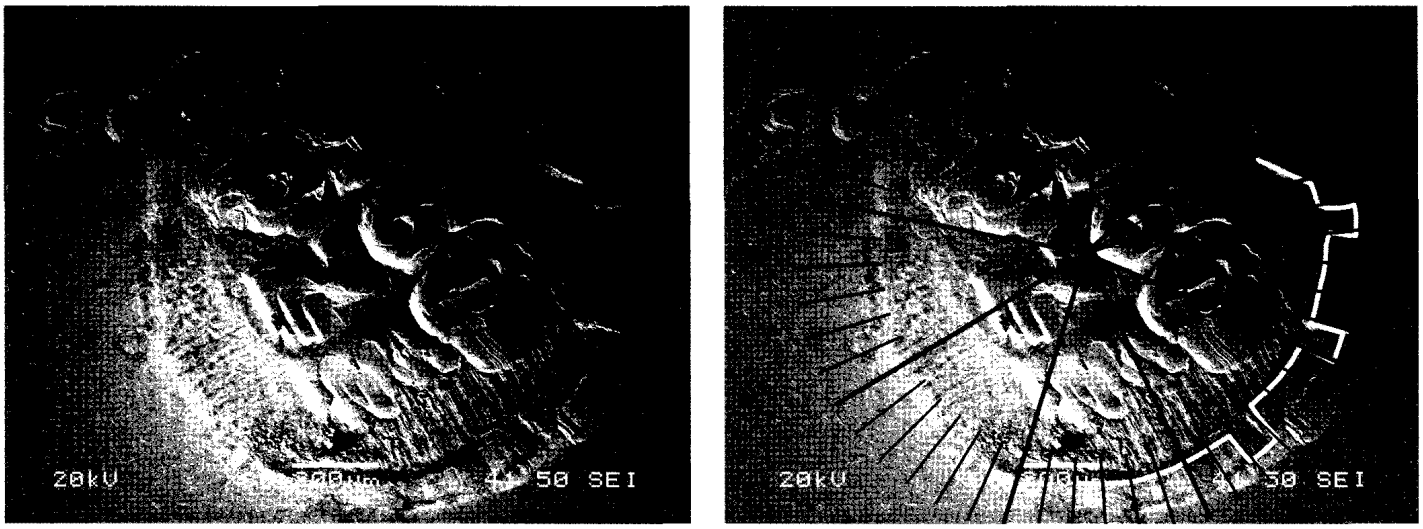

Figure 6: a) SEM image of a Hi-Point cartridge #610, left b) Outlined gear code and overlay, right

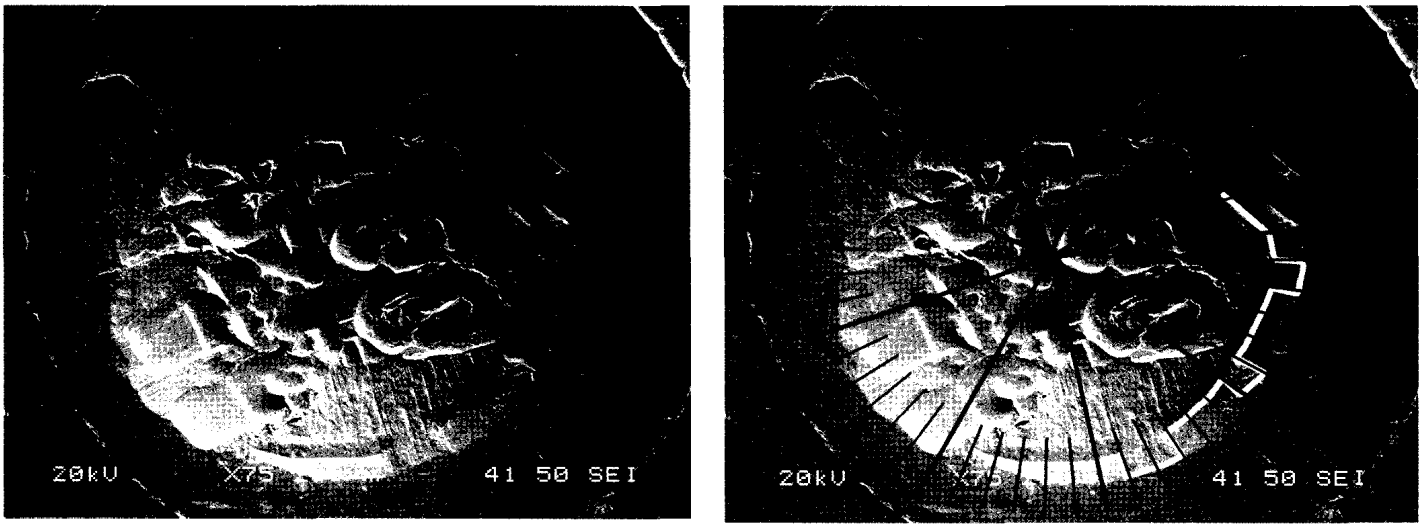

Figure 7: a) SEM image of Hi-Point cartridge #520, Silver Bear, left b) Outlined gear code and overlay, right

followed by Z, then maybe a 5. In this case the gear code lends valuable assistance and permits unambiguous identification of the first two sectors, which translate as "H" and "6", confirming the tentative assessment of the image. The third sector almost reveals the third identifier as "0", but the last bit of the gear code didn't transfer. However, since most of the "0" did transfer on the identifier, an examiner might conclude that the first three digit sequence is H60.

Like cartridge #610, cartridge #716 from the CorBon ammunition set also has an apparent erroneous gear code for the second digit. Optically, this cartridge was graded as C2, but three additional alpha-numerics are revealed through the SEM image. As seen in **Figure 8**, the first sector of the gear code reads correctly as 010001 (H), but again the second sector reads as 000100 (4). From the alpha-numerics that transferred, it's clear that the second alpha-numeric is actually a "6" and not "4" as the gear code suggests. The gear code corrects itself at the third sector and reads as 000000 (0). The gear code also correctly gives us the missing alpha-numeric, H, changing the overall clarity rating to C6. However, in a real-life setting the fact that the gear code does not match a corresponding clear alpha-numeric indicator casts doubt on any identification based on the gear code alone. Thus, while the entire code can be reconstructed, in all probability this identification would be disregarded as being unreliable. This instance points to a problem where an unclear marking of the gear code leads to a false interpretation.

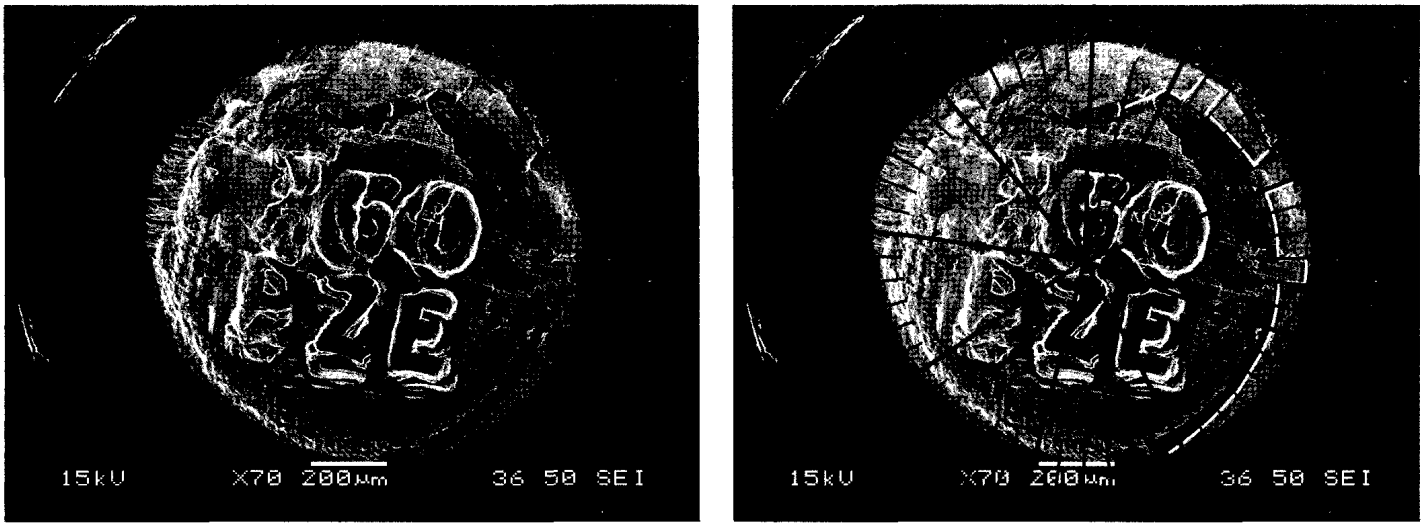

Figure 8: a) SEM image of Hi-Point cartridge #716, CorBon, left b) Outlined gear code and overlay, right

It is important to note at this point that the gear codes on the firing pins used for #610 and #716 are correct and that the error is introduced during the marking. Examination of both #610 and #716 using SEM show that both cartridges appear to have been double-struck. This presumably is the reason for the apparently erroneous gear code markings.

Lacquered Cartridges

Lacquered cartridges, from the Sellier & Bellot ammunition, posed problems during the optical and SEM evaluations, especially for the Hi-Point cartridges as it interfered with the transfer of the identifiers and the gear code. As seen in Figure 9, Sig Sauer cartridge #909 (S&B) does not have the clarity that the earlier cartridges did in either the alpha-numeric characters or the gear code. In fact, the only parts of the gear code that can be readily deciphered are the first and last sections, both of which read 011001 (S).

The slightly smeared Sig Sauer transfer described above still appears fairly clear, however, especially when compared to the poorest transfers from some of the Hi-Point cartridges. **Figure 10** is a good example of some of these transfers. Hi-Point cartridge #974 (S&B) in Figure 10a was graded optically as C0 and its grade only improves to C1 with SEM and gear code analysis. By comparison, the gear code on cartridge 937 did not fare as well as that of 974. The first half of the visible portion is wiped out, making any analysis of the gear code futile. However, the SEM analysis does yield another alpha-numeric character than the optical grade did, making the total clarity rating C2.

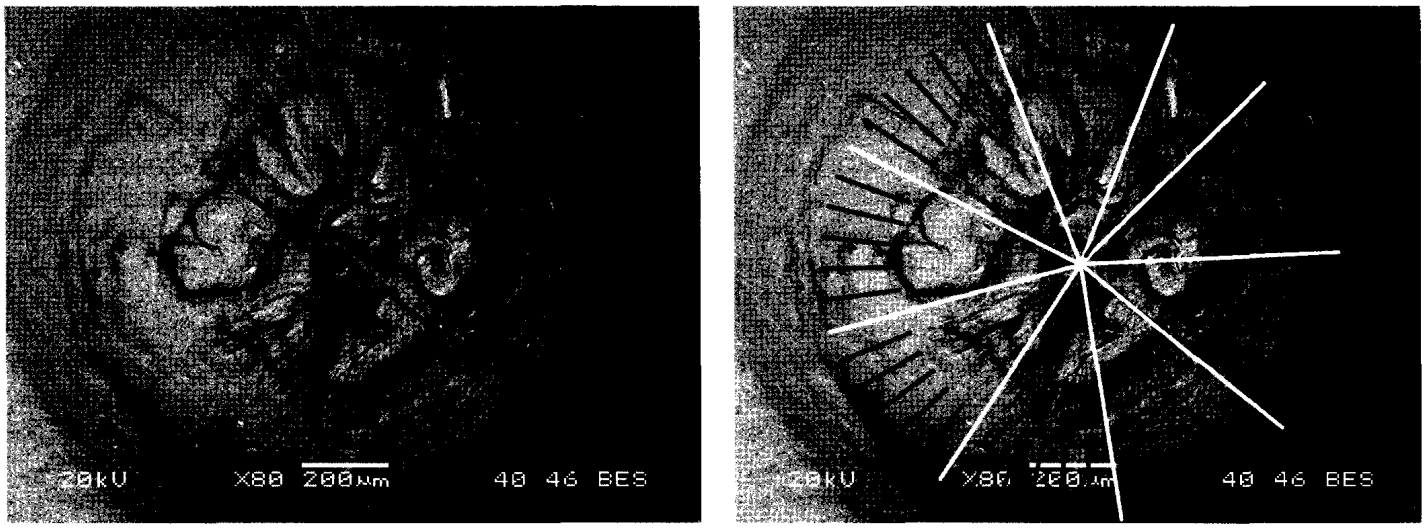

Figure 9: a) SEM image of Sig Sauer cartridge #909, S&B, left b) Outlined gear code and overlay, right

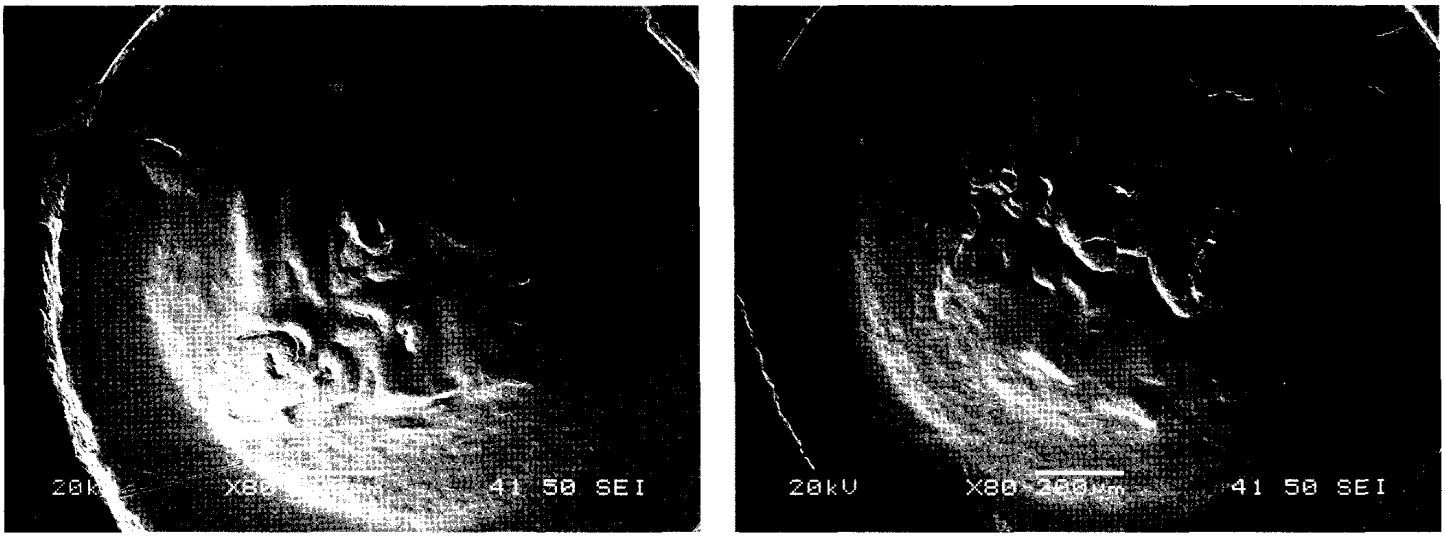

Figure 10: a) SEM image of HP cartridge #974, left b) SEM image of HP cartridge #937, right

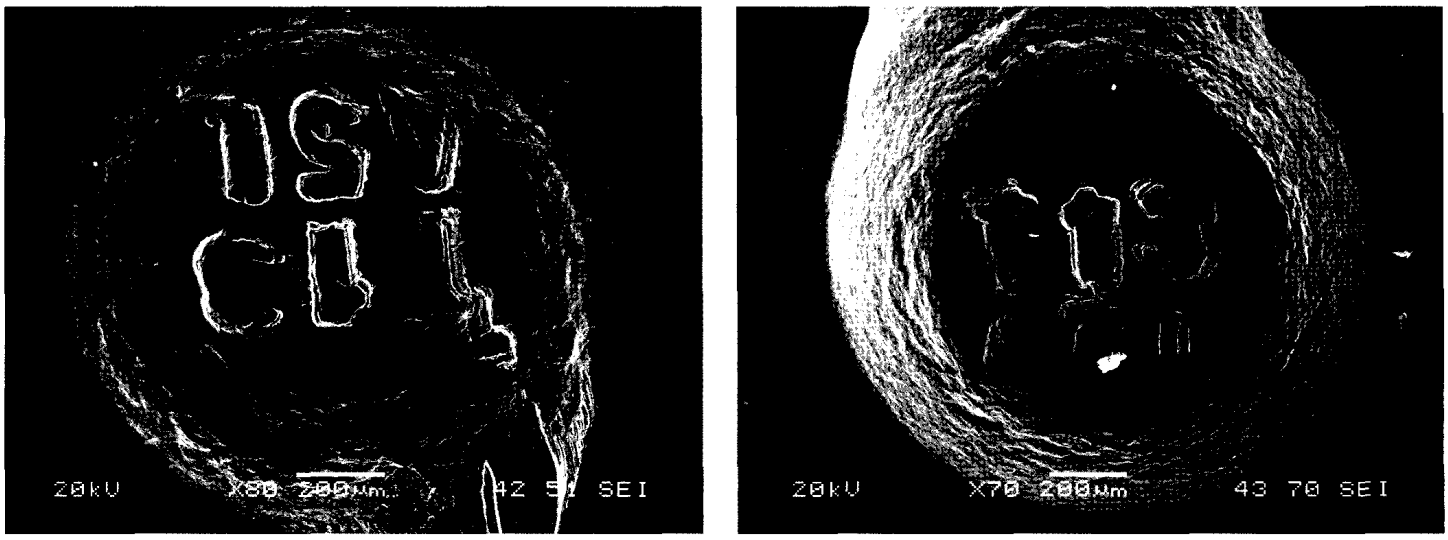

Figure 11: a) SEM image of Taurus cartridge #944, left b) SEM image of Taurus cartridge #945, right

Like the unlacquered cartridges, the lacquered Taurus cartridges showed poor gear code transfer, even to the extent of lacking the starting wedge marker (**Figure 11**). Though the lacquer smeared the alpha-numerics of the Hi-Point extensively, the Taurus did not exhibit such extreme distortion. As evidenced by **Figure 11**, the alpha-numerics are still legible. Cartridge #945 (S&B) shown in **Figure 11a** was graded optically as C3 and with SEM evaluation the total clarity grade conservatively becomes C4 and it could be argued a C6. Cartridge 944 was graded optically as C2, but all 6 alpha-numerics are visible in the SEM image.

Gear Code Analysis by Magazine

Often where a shooting has occurred several cartridge cases may be left behind. Assuming that the gun used was equipped with a microstamped firing pin, one argument made in defense of compiling, or adding, partially transferred markings is that given a large number of incompletely marked cartridges from (presumably) the same firearm, could the entire identifier be reconstructed? An analogy would be that part of an automobile license plate is better than no plate number at all. To examine this hypothesis, cartridges from two magazines from each gun were examined optically with a stereomicroscope, one from a non-lacquered ammunition set and the other from the lacquered S&B cartridges. Each magazine chosen had the highest number of non-C6 ratings to represent a possible worst case scenario. **Table III** summarizes the grades of the chosen magazines. The bold, capital X's denote both the alphanumeric character and its corresponding section of gear code were legible, the lower case, x's denote only the alphanumeric character having a clear transfer and GC

denotes only the gear code being decipherable. If the table is blank it means for that cartridge neither the alpha-numeric or gear code were decipherable.

Not surprisingly, the only complete alpha-numeric + gear code transfers occurred in the Sig Sauer, both unlacquered and lacquered. It should be noted, however, that due to the presence of lacquer in cartridges 901-1000, the transferred gear code was slightly smeared, but the code in many cases could still be deciphered.

The Taurus cartridges again did not have all of the gear code on the unlacquered cartridges, though they did assist in identifying the first one or two alphanumeric identifiers. The lacquered Taurus cartridges were largely unhelpful in examining the gear code. The Taurus firing pin's lack of surface relief combined with the lacquer coated primers caused no gear code transfer in the Sellier & Bellot cartridges. In some cases, even the start wedge of the gear code failed to transfer.

The Hi-Point gear codes were slightly more helpful than those of the Taurus. Still, the gear code transfer did not extend beyond the "0," and as evidenced by the table, in several cases did not transfer or did not transfer legibly.

Despite the poor performance in some cases, it is still apparent that if one knows or could safely assume that all ten cartridges found at a crime scene came from a single magazine of ammunition, the entire identifier could be reconstructed using the combined information for every magazine examined in this study.

Discussion

A summary of the results obtained in this study is shown in **Table IV** for the 26 cartridges examined. As seen in the table, simply using the SEM as an evaluation tool measurably increased the number of visible alpha-numerics, irrespective of the gear code. In fact, the gear code was only seen to increase the number of identifiable alpha-numerics in a single instance, although it could be argued perhaps that the gear code did confirm the guesses made based on SEM imaging. However, this help must be balanced with those cases where the gear code seemed to be at odds with the visual data from imaging (e.g. cartridges H610 and H716).

As mentioned, most of the improvement in scores came not by use of the gear code but by the improved imaging characteristics of the SEM. While this is encouraging, the SEM may not be readily available to forensic examiners. It is interesting that the majority of the gear codes tended to mark well in the initial sectors (e.g. up to the first three identifiers, especially with the Hi-Point and Taurus) but less well in the remaining ones. Unfortunately, the code in the missing regions often corresponded to the missing alpha-numerics, so the gear code rarely was able to clarify any uncertainties in the last three alpha-numerics. For the evaluated cartridges, the clarity of the transferred alpha-numerics as a function of position was examined to see if any trends existed that might guide placement of the gear code in such a manner as to better allow reconstruction of the missing alpha-numerics using the gear code, such as possibly a reversal of the gear code to run counter-clockwise rather than clockwise. While no clear trends were discernible from the limited amount of data obtained this remains an area worth investigating. If the firing / ejection mechanism of a particular handgun consistently produces a smearing of the alpha-numeric in a certain area, it might be possible to design the gear code such as to provide redundancy in an area that statistically provides good transfer clarity. Other possible areas to study include the effect of the shape of the firing pin as pertaining to size and radius of curvature at the tip; the average force exerted on the firing pin; and the effect of striker vs. hammer, etc. All these variables can be expected to play a role in the quality of transfer. While the cycle of fire protocol used to place the unique identifier on the firing pin ensured that the best possible transfer was achieved for the given set of conditions associated with that particular firearm, it does not identify the particular variable and/or define the optimum parameters in firearm design / manufacture that would ensure the best transfer of the alphanumeric and gear code. Such a study might also be worthwhile.

It should also be noted that the quality of the gear code transfer was not examined in cartridges that previously had received a rating of C6. Since the gear code is meant to be a backup for those who might seek to remove the alpha-numeric code at the tip, this also is an area of further study. A study of determining the identifier based solely on the gear code is planned for the future.

Conclusions

This study investigated the transfer of a digital circumferential gear code placed on the end of the firing pin of three different firearms. As seen in a previous study that only evaluated the quality of alpha-numeric transfer, this study showed that gear code transfer was not universal. However, with partial information from both the identifiers and the gear code, some identification can be made, especially when the information discernable from the gear code does not overlap that provided by the readable alpha-numerics. That being said, a full gear code appears to be rare and dependent on the weapon that

Hi-Point														
	Unlacquered								Lacquered (S&B)					
Ctg.	H	6	0	P	Z	E		Ctg.	H	6	0	P	Z	E
571	X	X	X	x	x	x		981	X	X	X		x	
572	X	X	x	x	x			982	x	x			x	
573		X		x	x			983	x	x			x	x
574		x	x		x	x		984	GC	x	x		x	x
575	x	x	x					985	GC	x	x			x
576	x		x	x	x			986	GC	X	X	x		
577	x	x	x	x	x	x		987	x		X	x	x	x
578		X	X	x		x		988	X	X	X	x	x	x
579		x			x	x		989	GC	X	X		x	x
580	x	x	x	x	x	x		990	x					
Taurus														
	Unlacquered								Lacquered (S&B)					
Ctg.	T	1	3	A	5	L		Ctg.	T	1	3	A	5	L
571	X	x	x	x	x	x		911	x	x	x	x	x	x
572	X	X	x	x	x	x		912		x	x	x		x
573	X	X	x		x	x		913	x	x	x	x	x	x
574	X	X	x	x	x	x		914	x	x	x	x	x	x
575	x	x	x	x	x			915	x	x	x	x	x	x
576	X	x	x		x	x		916	x	x	x	x	x	x
577	X	X	x	x	x	x		917		x	x	x	x	x
578	X	X	x	x	x	x		918	x	x	x	x	x	x
579	X	X	x	x	x	x		919		x	x	x	x	x
580	X	x	x		x	x		920	x	x	x		x	
Sig Sauer														
	Unlacquered								Lacquered (S&B)					
Ctg.	S	2	3	S	X	7		Ctg.	S	2	3	S	X	7
191	X	X	X	X	X	X		911	X	x		x	x	
192	X	X	X	X	X	X		912	X	X	X	X	X	X
193	X	X	X	X	X	X		913	x	X	X	X	X	X
194	X	X	X	X	X	X		914	x	x	x	x	x	x
195	X	X	X	X	X	X		915	X	X	x	x	X	X
196	X	X	X	X	X	X		916	X	X	X	X	X	X
197	X	X	X	X	X	x		917	X	X	x	x	x	x
198	X	GC	X	X	GC	X		918	x	x	x	x	x	x
199	X	X	GC	x	GC	GC		919	x	x	x		x	x
200	X	X	X	X	X	X		920	x	x	x		x	x

Table III: Summary of gear code and alphanumeric character evaluation from low grade magazines

Sig Sauer					
Ctg. #	**Brand**	**Optical grade**	**SEM grade**	**Gear Code**	**Total Identifiers**
10	Brown Bear	C1	C3	C5	C6
24	Brown Bear	C2	C6	C6	C6
707	CorBon	C0	C2	C2	C3
908	S&B	C0	C2	C1	C2
965	S&B	C4	C4	C0	C4
985	S&B	C4	C6	C0	C6
Taurus					
Ctg. #	**Brand**	**Optical grade**	**SEM grade**	**Gear Code**	**Total Identifiers**
101	DAG	C5	C6	C0	C6
233	Amer. Eagle	C2	C3	C2	C3
275	Amer. Eagle	C5	C5	C0	C5
282	Amer. Eagle	C2	C3	C0	C3
296	Amer. Eagle	C1	C2	C1	C2
944	S&B	C2	C6	C0	C6
945	S&B	C3	C4	C0	C4
Hi-Point					
Ctg. #	**Brand**	**Optical grade**	**SEM grade**	**Gear Code**	**Total Identifiers**
164	DAG	C1	C6	C1	C6
218	Amer. Eagle	C2	C3	C0	C3
420	PMC	C2	C6	C3	C6
520	Silver Bear	C0	C3	C2	C4
541	Silver Bear	C1	C5	C0	C5
573	Silver Bear	C2	C6	C3	C6
716	CorBon	C2	C5	C1	C6
880	Independence	C2	C6	C3	C6
910	S&B	C2	C4	C0	C4
937	S&B	C1	C2	C0	C2
974	S&B	C0	C1	C1	C1

Table IV: Summary of grades from optical and SEM assessments

made the impression. Also problematic was the gear code appeared to be at odds with the alpha-numeric in certain instances. While the latter appears to be related to double strikes, which can be recognized by an examiner, the former problem requires more study concerning exactly what combination of type of mechanism / pin / action / minimum pressure etc. is most likely to produce good transfer.

While large pieces of the gear code did not transfer in many cases, SEM evaluation greatly improved the clarity ratings for nearly all selected cartridges. This suggests that simply equipping labs with small, relatively inexpensive SEMs (simple models can be had for ≈ 50K) may be more cost effective than extensive research and development of improved gear code transfer.

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