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Comparing the Performance of IBIS and BulletTRAX-3D Technology Using Bullets Fired Through 10 Consecutively Rifled Barrels*

ABSTRACT: This study evaluates the abilities of the Integrated Ballistics Identification System (IBIS) and BulletTRAX-3D electronic imaging systems to identify bullets fired by the same weapon in a large database of images. Ten consecutively rifled handgun barrels were test fired to obtain reference sample and known match sample pairs for upload onto both bullet acquisition systems. Both copper-jacketed and lead bullets were uploaded, to account for variations in the manner in which markings are reproduced on the different metal compositions. Ranked correlation lists were examined and evaluated. For copper-jacketed bullet correlations, both IBIS and BulletTRAX-3D identified all reference samples to their known matches within the top 10 positions. For lead bullets, BulletTRAX-3D identified all reference samples to their known match in the top 10 positions while IBIS identified only 30%. For inter composition comparisons, BulletTRAX-3D was more successful than IBIS, identifying 100% of reference samples to their known match in the top 20 for copper-jacketed to lead comparisons and 90% for lead to copper-jacketed comparisons. These results suggest that BulletTRAX-3D is more effective than IBIS in the analysis of a wider range of bullet types and it was also found to produce images of superior quality.

KEYWORDS: forensic science, integrated ballistics identification system, BulletTRAX-3D, fired bullets

The Integrated Ballistic Identification System (IBIS) is a screening tool used in forensic firearms examinations that allows for the rapid acquisition of digital images of fired ammunition components. Since its introduction in the mid-1990s, it has become the worldwide standard for the electronic imaging and comparison of fired cartridge cases and bullets (1). Manufactured by Forensic Technology Inc. (FTI), it is used in numerous countries in an effort to link firearm related crimes, and has significantly reduced the time spent performing manual comparisons.

Digital images of ammunition components are uploaded onto the IBIS system and through a series of filters their signatures are mathematically compared with a correlation score that is used to rank them by their degree of similarity. The operator can then visually compare the images of the items that rank highly in the correlation list to identify potential "hits" for forensic examination.

Many studies have been conducted to evaluate the effectiveness of IBIS correlations on cartridge cases (2–4), but few have assessed its effectiveness with bullets. Bachrach (5) asserts that the identification of bullets by systems like IBIS have not yet met the expectations of the firearms examiner. Results in the Firearms Section of the Centre of Forensic Sciences (CFS) support this, as hits are generated more frequently on cartridge cases than on bullets. In fact, since IBIS was implemented in our laboratory in 2004, there have been 502 recorded hits on cartridge cases but none on bullets. This may be due to the nature of two dimensional image acquisition and Bacharach (5) suggests that better characterization of the bullet's surface by 3D imaging should translate into better performance of the automated imaging system. Thompson (6) agrees that the features that an examiner considers during the examination of an item such as a bullet cannot be accurately captured in a 2D image.

BulletTRAX-3D (also manufactured by FTI) is an automated, bullet-evidence acquisition station that is similar to IBIS, but unlike IBIS uses both 2D and 3D imaging technology. It utilizes a specially designed 3D confocal sensor that can capture a digital image and create a 3D topographic model of the surface of a bullet. As well as taking images, it allows the user to make quantitative measurements of a bullet's surface.

The purpose of this study was to evaluate the performance of both IBIS and BulletTRAX-3D in the acquisition of fired bullets. It assessed the ability of IBIS and BulletTRAX-3D to correctly identify a hit, and also determine where in the correlation list that hit lies. It further examined the quality of the images produced by each system, as an operator uses visual comparisons in conjunction with correlation rankings to aid in the identification of potential matches. The study sought to determine whether newer 3D imaging technology produces better results than 2D technology, which is an important consideration for any lab considering the acquisition of an automated bullet comparison system.

Materials and Methods

Ammunition and Test Firing

Slide assemblies of 10 barrels were acquired from Para-Ordnance in Markham, Ontario. The slide assemblies consisted of the top end of the firearm, including the slide, barrel, firing pin, extractor, and breech face. The barrels were manufactured for the model P10-45 semi-automatic pistol, trade name "Warthog" with the design characteristics of 45 caliber, six lands and grooves, and a left-hand twist. The land and groove widths were 0.07 and 0.157 inches, respectively. The manufacturer gave the assurance that the barrels were broached, the chambers reamed, the extractors moulded, the breech faces machined and the firing pins were manufactured

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consecutively. It was also noted that the components were assembled so that each top end was manufactured in order and was not tested fired prior to leaving the factory. The receiver used for test firing was a Para-Ordnance Model P10-45, taken from the CFS reference collection.

The 10 consecutively manufactured barrels were test fired into a water recovery tank at the CFS Firearms and Toolmarks section over a 1-week period. The ammunition selected for test firing was Remington UMC 230GR, full metal, copper-jacketed, round nose bullet and Can-north commercially reloaded 200GR, semi wad cutter, and lead bullet. One pair of copper-jacketed bullets and one pair of lead bullets were selected from those generated and labeled by letter-number, the letter designating the barrel from which the item was fired and numbers 1 and 2 designating the copper-jacketed pair of bullets and number 3 and 4 designating the lead pair.

The fired ammunition components were examined by a qualified scientist who confirmed that there were sufficient markings present to identify each of the barrels and ensured that there were suitable characteristics present in the test fires for upload onto IBIS/BulletTRAX-3D.

Bullet Upload

An IBIS system consisting of a remote data acquisition station (RDAS) and signature analysis station (SAS), version 3.4.5 was used to upload the bullet images following specific guidelines set out in FTI's Training Guide (7). To ensure reliability and consistency, all bullets were uploaded by the same FTI trained and experienced operator. One copper-jacketed and one lead bullet from each barrel were uploaded onto IBIS as reference samples. The second copper-jacketed and lead bullets from each barrel were then uploaded as known match samples in an attempt to link them to the reference samples.

A BulletTRAX-3D system consisting of an automated acquisition unit, computer workstation, and high-resolution flat screen display, version 2.0 was used to upload the same set of bullets as on IBIS, again following guidelines set out by FTI. To improve efficiency during data collection, a second BulletTRAX-3D system was used simultaneously in order to upload the lead bullets two at a time. For consistency, all bullet images were uploaded by the same experienced operator as uploaded the IBIS images.

The Database and Correlations

The databases used in this study were provided by FTI and each contained 475 entries of various 45 caliber bullets with six lands and grooves, land widths ranging from 0.057 to 0.095 inches and a left-hand twist. Each database was comprised of the same samples, with one database created by acquiring images onto IBIS and the other by acquiring images onto BulletTRAX-3D. They were created of equal size and content to maintain consistency and to allow for an accurate comparison of the two systems.

Correlations were performed against the database as per guidelines set out by the manufacturer. For the purposes of this study, correlations were performed until the known match sample was found. Because the IBIS correlator only produces a list of the most similar items in the database, a particular correlation may only be considered unsuccessful when the known match does not appear in the correlation list at all. As only the top 20 positions of the correlation list are examined at the CFS, an operator would likely not identify any potential matches that fall outside of this range. Thus, for practical purposes in this study, known matches appearing in the correlation list outside of the top 20 positions were considered unsuccessful.

The same operator who uploaded the bullet images carried out all correlations. These correlations were examined for the reference samples of both the copper-jacketed and lead bullets to identify where known match samples were located in the correlation list (e.g., top 10, top 20, etc.). For inter composition comparisons, the correlation list for each reference bullet was reviewed to determine the position of the matching bullet of different composition (i.e., copper-jacketed bullets compared against lead and vice versa). For example, the correlation list for each copper-jacketed bullet was examined to determine where the first lead bullet match appeared.

IBIS generates many different scores during correlation depending on what areas of the bullets are being compared. In this study, data was collected for all IBIS and BulletTRAX-3D scores including Max Phase, Peak Phase, Max LEA, and Peak 3D; however, only the results of the Max Phase and Peak 3D scores are reported on in this paper. Max Phase is the highest score of the bullet-to-bullet correlation, where the phase refers to the alignment of the land engraved areas (LEAs) between two bullets. Peak 3D is the highest 3D LEA-to-LEA score between the two bullets. Max Phase and Peak 3D are generally considered to be the most important scores as Max Phase is the only score that takes the entire bullet (all LEAs) into consideration and Peak 3D is the lone 3D score. As a result, these scores are most often the highest and reflect the bullet comparison most accurately.

Results

Copper-Jacketed Bullet Comparisons

For Max Phase, IBIS correlated 100% of the reference samples to their known match within the top 10 positions, with 90% of those matches occurring in the first position. For the one match that IBIS did not locate in the first position, a bullet fired from a different Para-Ordnance barrel (I1) was located in a higher position than the reference bullet. For Phase 3D, BulletTRAX-3D correlated 100% of the reference samples to their known match in the top 10, all in the first position (Table 1). Thus, by CFS standards and the

TABLE 1—*Frequency (%) that reference samples and known matches were identified and their location in the correlation list for copper vs. copper and lead vs. lead bullets in both IBIS and BulletTrax TRAX-3D.*

	Copper vs. copper			Lead vs. lead		
	Top 10 (1st Position)	Positions 11–20	Outside top 20	Top 10 (1st position)	Positions 11–20	Outside top 20
IBIS	100 (90)	10	0	30 (0)	0	70
BulletTRAX-3D	100 (100)	0	0	100 (70)	0	0

parameters of this study, both systems can be considered to be successful in the identification of known copper-jacketed pairs.

In evaluating image quality, both IBIS and BulletTRAX-3D produced images of sufficient quality that an operator could easily identify the matches. The ease at which an operator could identify a potential match however, was greatly increased when the 3D images were examined. This result is consistent with the fact that the amount of topographic detail obtainable in three dimensions is greater than in two dimensions (Figs. 1 and 2).

A previous study of 10 consecutively rifled barrels done by FTI (8), considered correlated pairs with a Max Phase score higher than 650 to be a high confidence match. All Max Phase scores in this study were found to be significantly higher than that—especially for the copper-jacketed bullets. The lowest Max Phase score for an IBIS match of copper-jacketed bullets was 815 and the highest was 1711. The lowest Max Phase score for a BulletTRAX-3D match of copper-jacketed bullets was 764 and the highest was 1142. These scores further illustrate how successful both systems were at identifying the known copper-jacketed pairs. It should be noted that Max Phase scores are unitless values that are intended to reflect the relative similarity between the reference and other samples in the correlation list. They cannot be used for inter-comparison between IBIS and BulletTRAX-3D. In other words, a high IBIS score versus a lower BulletTRAX-3D score does not infer a more successful comparison.

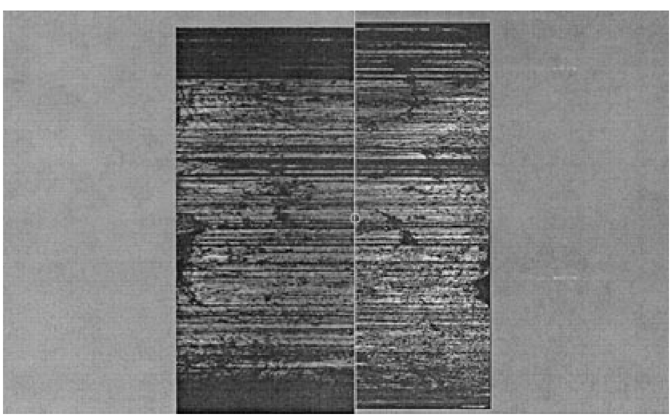

FIG. 1—*IBIS comparison image of reference sample (E1) and known match (E2) copper-jacketed bullets.*

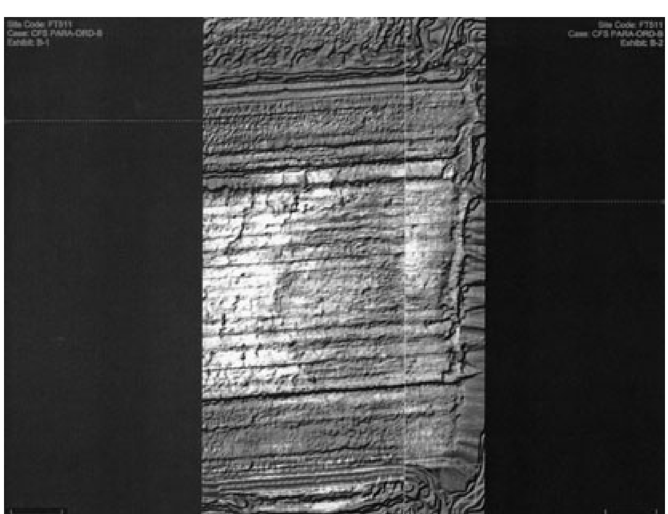

FIG. 2—*BulletTRAX-3D comparison image of reference sample (B1) and known match (B2) copper-jacketed bullets.*

Lead Bullet Comparisons

Identification of lead bullet pairs was much more successful using BulletTRAX-3D than IBIS. For Max Phase, IBIS correlated 70% of the reference samples to their known matches outside of the top 20 positions (Table 1). This falls outside of the zone of search that the CFS follows and that FTI recommends, meaning that 70% of potential matches would likely not be identified. Analysis of the correlation list further shows that IBIS identified at least one bullet fired by a different Para-Ordnance barrel higher in the list than the reference barrel in 90% of comparisons. Image quality of the lead bullets in IBIS is also inferior to those in BulletTRAX-3D. Of the reference samples that did correlate to their known matches within the Top 10 positions, the image quality of the bullet surface was so poor that it is unlikely that any pair would be visually identified by an operator as being a possible match (Fig. 3).

BulletTRAX-3D on the other hand, identified all reference samples to their known matches within the zone of search. For Phase 3D, BulletTrax TRAX-3D correlated 100% of reference samples to their known matches within the top 10 positions, with 70% in the first position (Table 1) and 30% in either the second or third position. Although BulletTRAX-3D did not identify all lead pairs in the first position, it did identify all bullets fired from the correct reference Para-Ordnance barrel in the first position. For example, in all the three instances where the lead bullet was in the second or third position, the matching bullet of different composition was in the first position. In the one instance where the lead bullet was in the third position, there was a different Para-Ordnance barrel in the second position. Image quality, especially the quantity of detail was also much better than with IBIS. Although the images were not as detailed as the copper bullet comparisons, enough information was visible for an operator to be able to identify a possible match (Fig. 4).

Inter-Composition Bullet Comparisons

For Max Phase, copper jacket to lead comparisons, IBIS correlated 80% of reference samples to their known match outside of the top 20 positions. IBIS scores were slightly improved for Max Phase, lead to copper jacket comparisons, with 60% of reference samples correlating to their known match within the top 20

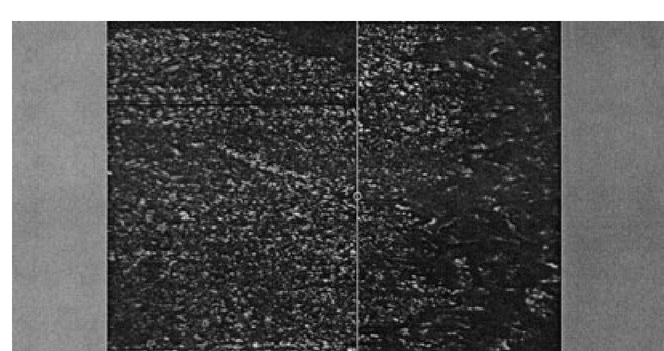

FIG. 3—*IBIS comparison image of reference sample (C3) and known match (C4) lead bullets.*

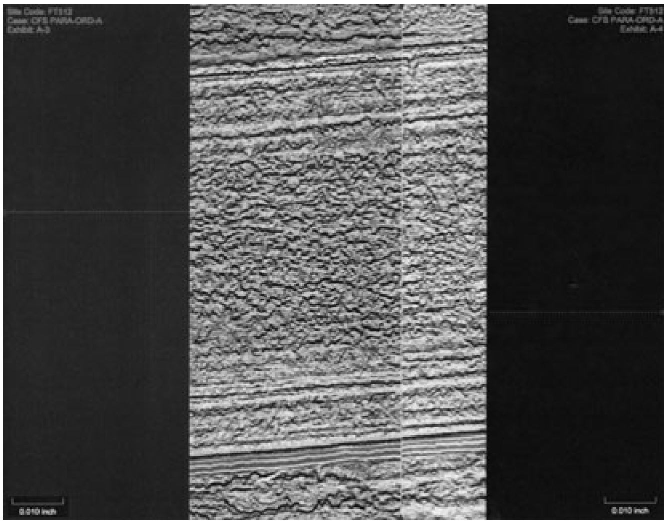

FIG. 4—*BulletTRAX-3D comparison image of reference sample (A3) and known match (A4) lead bullets.*

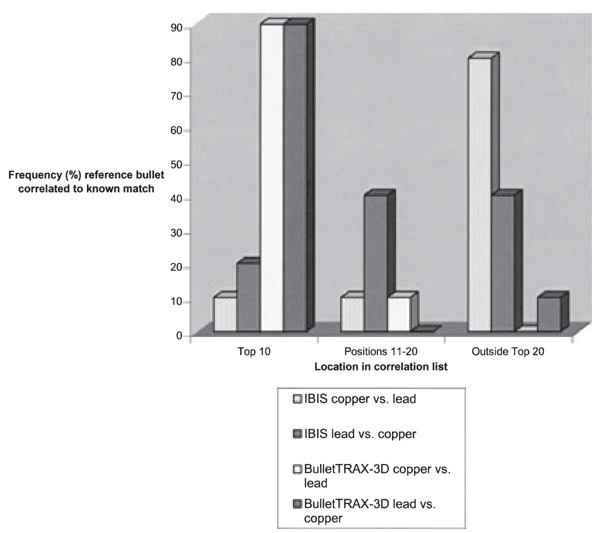

FIG. 5—*Frequency (%) that reference samples and known matches were identified and their location in the correlation list for inter-composition bullets in both IBIS and BulletTrax TRAX-3D.*

positions (Fig. 5). Thus for IBIS inter-composition comparisons, numerous samples were located outside the correlation area of search and would likely result in many missed hits. IBIS was also less able to distinguish between inter-composition bullets fired from the different Para-Ordnance barrels as 100% of comparisons found a bullet fired from a different barrel higher in the correlation list. IBIS image quality for lead bullets was poor, and as such there was little value in comparing those images with more detailed copper-jacketed images. An operator would likely not be able to identify a possible match between the lead and copper-jacketed bullet pairs (Fig. 6).

BulletTRAX-3D was more successful than IBIS at identifying matches within the inter-composition comparisons. In copper jacket to lead comparisons, 100% of reference samples were correlated to their known matches within the top 20 positions (90% of matches were within the top 10). For lead to copper jacket comparisons, BulletTRAX-3D correlated 90% of reference samples to their known match within the top 10 and the remaining 10% outside

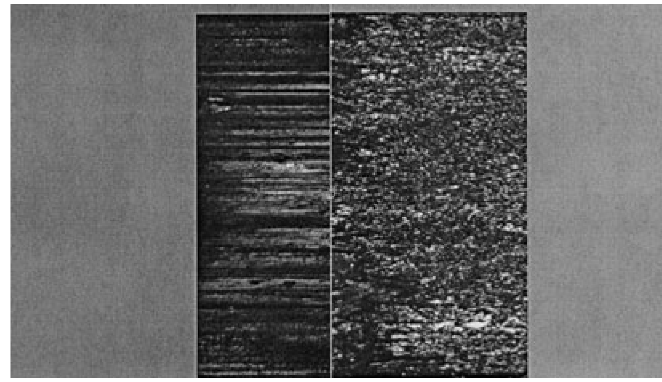

FIG. 6—*IBIS comparison image of reference sample (B2) copper-jacketed bullet and known match (B3) lead bullet.*

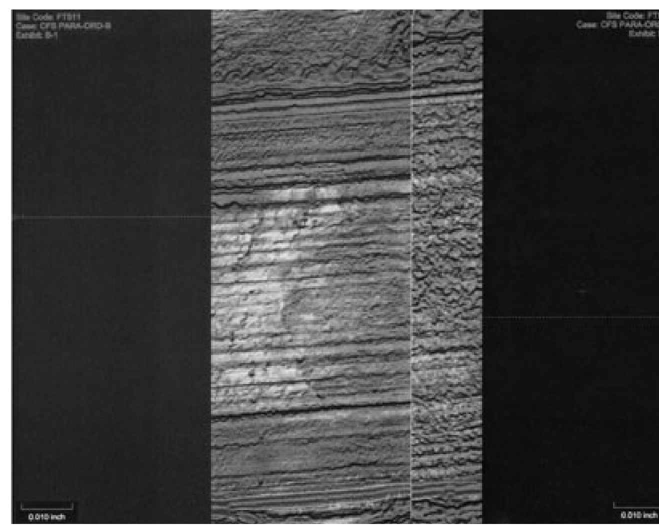

FIG. 7—*BulletTRAX-3D comparison image of reference sample (B1) copper-jacketed bullet and known match (B4) lead bullet.*

of the top 20 (Fig. 5). For inter-composition comparisons, BulletTRAX-3D was successful at distinguishing between the different Para-Ordnance barrels as 90% of comparisons found the bullet fired from the reference barrel in the first position in the correlation list. Image quality was also better using BulletTRAX-3D. Although visual identification of the inter-composition bullet pairs is more difficult than with bullets of the same composition, it is possible for an operator to find enough details in common to identify a potential hit (Fig. 7).

Discussion

One of the most important factors in the success rate of the IBIS correlator is the size of the database used for correlations, as the success rate has been shown to decrease as database size increases (1). It is important to use a database of sufficient size, however, to properly evaluate the two systems. Before a bullet can be compared by either IBIS or BulletTRAX-3D, it must first be determined to have the same class characteristics. These are design features that are chosen by the manufacturer and include caliber, number, width of lands and grooves, and direction of twist. All 475 bullets in the database used in this study consisted of identical class characteristics, with the exception of LEA and groove engraved area (GEA) widths, which vary. LEA widths of the database bullets ranged from 0.057 to 0.095 inches and the Para-Ordnance bullets had a LEA width range of 0.070 to 0.079 inches. However, IBIS has a LEA width tolerance of +/−10%. That means that it will compare bullets that have at least one LEA width either 10% narrower than the narrowest LEA or 10% wider than the widest LEA of the reference bullet in question. When taking this tolerance into account, there were only two bullets in the database that were completely excluded (no LEAs from the bullet fell within the 10% tolerance) from comparison based on LEA width, leaving 473 bullets suitable for comparison. It should be noted that IBIS does not make exclusions based on GEA width and BulletTRAX-3D does not make exclusions based on either LEA or GEA width, but instead exclusions are based on topography. The database used in this study contained a larger number of 45 caliber, six land and groove, left-hand twist bullets than are currently in the database at the CFS in an effort to provide a realistic challenge in the evaluation of the two systems.

The success rate of the IBIS correlator has been shown to increase as the quality of markings or striae imparted by the firearm onto the ammunition components increases (1). Two different bullet compositions were employed in this study to evaluate the impact of marking quality. Lead, being a much softer metal than copper, produces marks of a poorer quality and therefore, provides a more rigorous test of the ability of the systems to identify known matches. The lead bullets in this study retained less individual striae than the copper-jacketed bullets. This translated into less detailed images being generated in both systems and also resulted in known matches being located further down in the correlation list. The quality of markings had only a marginal impact on BulletTRAX-3D, as performance was only slightly affected during inter-composition comparisons. The capture of less surface detail for the lead bullets was much more pronounced with IBIS where numerous matches were considered unsuccessful for both lead-to-lead and inter-composition comparisons. Overall, BulletTRAX-3D was found to be more successful than IBIS at identifying both lead-to-lead and inter-composition bullet matches in the top 20 positions and producing images of high quality. Image quality is of critical importance to an operator as it can be the deciding factor as to whether a pair of images is selected for further examination by a forensic scientist. In cases, where there are no obvious high correlation scores between the bullets ranked in the top 20, image comparison is essential for the identification of possible hits.

The concept of individuality of striae reproduced on fired bullets is an integral part of firearms identification, and is based on the principle that no two firearms will impart the same markings on bullets and cartridge cases. It has been shown that the most similarity between bullets, however, will be found on those fired through consecutively rifled barrels (9). This is because of the fact that the working surfaces of the tools that produced the barrels would have changed only slightly over such a short period. The similarity seen is dependent on the type of rifling method used and any finishing steps that may have been applied after rifling. The Para-Ordnance barrels were manufactured using a cut broaching method. The use of this type of rifling method may result in the most similar markings occurring within the groove impressions rather than the land impressions. However, the rifling was followed by a finishing process called ball burnishing. This process involves forcing a hardened steel ball through the barrel to smooth the tops of the lands and could also cause similarities to carry over into the land impressions. As a result, the comparison of the 10 consecutively rifled barrels in this study tests the abilities of the two systems to differentiate between bullets fired from very similar barrels.

For copper jacket comparisons, IBIS was successful in the identification of the correct barrel. For lead-to-lead and inter-composition comparisons, IBIS was less successful at distinguishing between the similarities, as there were bullets of a different Para-Ordnance barrel appearing higher in the correlation list than those of the reference barrel in all comparisons. BulletTRAX-3D was able to successfully distinguish the similarities between the copper jacket-to-copper jacket, lead-to-lead, and inter-composition comparisons. The fact that BulletTRAX-3D uploads and correlates both the LEA and GEA areas of each bullet, demonstrates its ability to successfully distinguish the similarities present on the surface of an entire bullet.

When interpreting correlation results, FTI suggests that a gap in scores should be identified (7). The gap is defined as a "jump" in the progression of scores that becomes obvious when they are listed in descending order. It is recommended that candidates appearing above and below the gap be compared. In the absence of a noticeable gap, it is suggested that at least the top 5–10 candidates be compared for Max Phase, Peak Phase, and Max LEA scores.

Although FTI claims that most matches are found in the top 10 items in the correlation list, there is no consensus as to whether correlations should be examined outside the top 10. For instance, George (2) found that correlating the top 10 was insufficient given that 75% of known matches in his study fell outside the list and 45% of known matches fell outside of the top 20 positions. Silverwater et al. (4) found the evaluation of the top five correlations to be sufficient in his study. Unfortunately, both of these studies were performed on cartridge cases alone. At the CFS, at least the top 20 candidates in the list are examined for all correlations. Based on the experience of finding hits outside the top 10, this more extensive examination is employed in an attempt to identify those hits that appear further down the correlation list.

This study demonstrates that based on a correlation range of the top 20 positions, IBIS is an effective tool for the detection of hits for copper jacket to copper jacket comparisons only. For all other comparisons (lead to lead and inter-composition), IBIS located known matches outside of the top 20 positions from 40% to 80% of the time. Since bullet composition in casework will include lead bullets, it can be assumed that hits will be missed unless an adequate range of the correlation list is searched. The results of this study strongly indicate that IBIS is not an effective screening tool for these types of comparisons.

The practice of examining the top 20 correlation candidates is suitable for bullet comparisons using BulletTRAX-3D. Although there is the potential to miss a hit that falls outside of the top 20 while using BulletTRAX-3D, the probability of such an event is greatly reduced as it successfully identified 100% of the matches within the top 20 positions for all comparisons except lead to copper jacket, which located 90% of matches in the top 20.

Aside from BulletTRAX-3D's demonstrated ability to accurately identify known matches, there are other considerations that make the system appealing. BulletTRAX-3D is easy to learn and requires much less operator involvement than IBIS, as acquisition is almost completely automated. Although it takes over 20 min to fully upload one 45 caliber bullet, the operator is initially only required to enter the case details and bullet parameters, after which the system can be left to acquire the bullet unattended. After acquisition, final positioning of the LEA anchors (LEA borders) is required by the operator in order to confirm that the acquired widths of each LEA are correct. These steps would likely only take a trained operator about 5 min to perform.

BulletTRAX-3D also has additional features that are not available with IBIS. This includes a consecutively matching striations

(CMS) function, filograph feature and on-screen ruler, which allow the operator to quantitatively assess the bullet images. The CMS function counts and color codes the consecutive striations according to the number of striations in agreement between two bullets. The filograph feature is a graphical representation of the topography of the two bullets being compared. The on-screen ruler allows the operator to take measurements of any desired distance on the screen, including LEAs, GEAs, or any distance in between. While these features may have potential for the quantitative analysis of images, they were not tested during this study.

There are also features that enhance image quality and may assist an operator in the identification of potential matches. These features include the ability to change the lighting angle and the degree of three dimensionality of an image after it has been acquired. This flexibility allows an operator to view the image under differing conditions, which may compensate for individual operator variability and preferences. BulletTRAX-3D further offers an "unwrapped" view of each bullet, so that all LEAs and GEAs are visible at once.

Finally, BulletTRAX-3D is fully compatible with IBIS because it records the bullet image in both two and three dimensions, and as such it can use the 2D image for comparisons with those that were initially uploaded onto IBIS. This is an important consideration for any lab that is looking to switch from IBIS to BulletTRAX-3D.

While IBIS is successful in the analysis of undamaged, copper-jacketed bullets, its performance is inferior to BulletTRAX-3D when lead bullets or bullets of differing compositions are compared. Thus, for laboratories investigating a switch to newer 3D technology, the results of this study suggest that BulletTRAX-3D is more effective than IBIS in the analysis of a wider range of bullet types, it is more sensitive to the subtle differences between very similar bullets, and also produces images of superior quality. Further study is required to examine the performance of the system when damaged or fragmented bullets are uploaded.

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