Firearms/Toolmarks Unit (FTU)
Validation Summary of Virtual Comparison Microscopy using Cadre TopMatch-GS 3D

Purpose

The purpose of this validation is to determine if 3D toolmark topographical instruments (Cadre TopMatch-GS 3D) can be utilized to perform virtual comparison microscopy of cartridge cases and demonstrate their reproducibility and reliability of results when determining common source.

Terms

- 3D toolmark topographical instrument: A device that can measure and record the x, y, and z positions of microscopic features contained within a toolmark and produce a digital reproduction of the toolmark.
- Toolmark: Impressed and/or striated feature(s) created when a tool (harder object) makes forceful contact with an item (softer object) transferring physical and/or microscopic features.
- Light Comparison Microscopy (LCM): The use of two-bridged compound microscopes to compare and evaluate microscopic features between two toolmarks.
- Virtual Comparison Microscopy (VCM): The use of software to compare and evaluate the digital reproduction of microscopic features between two toolmarks.
- Ground Truth (GT): The source of a sample is known.
- False Positive: Result recorded as "Identification" when the ground truth is an Elimination.
- False Negative: Result recorded as "Elimination" when the ground truth is an Identification.

Validation Plan

Phase I - Assessment of previously deployed Proficiency Tests
Start Date: July, 2015

The FTU has a collection of firearm and toolmark proficiency test packets from 2003 to the present. Originally, these tests were deployed as part of the FTU proficiency testing program and were examined by qualified examiners using traditional LCM. The results of these LCM examinations are known. For Phase I, the following method was used to validate VCM using proficiency tests:

- Firearm proficiency tests were identified, collected and maintained within the FTU research room.
    - Proficiency tests containing cartridge cases were isolated for analysis.
- Each test and cartridge case was given a unique identifier different from the manufacturer's original design to prevent examiners from recognizing them from previous deployment.

  - All samples provided in a proficiency test were used for VCM, to include the three known samples submitted by the test provider.
  - Cartridge cases were scanned using the TopMatch-GS 3D instrument.
    - Proficiency tests containing sample scans were initially collected for system performance using silver laminate reflective surface - "Grey Gel" in July 25, 2014.
    - GelSight introduced new iron oxide laminate reflective surface - "Red Gel" in May 26, 2015.
    - Proficiency test samples were rescanned using the red gel for VCM validation.
- For VCM validation, the software was re-configured by Cadre TopMatch for one-to-one VCM. Additionally, access to the system's algorithm was blocked to prevent any bias in the examiner's decision.
- February, 2016 Examiners were given instruction on how to operate Cadre TopMatch-GS 3D software to perform a VCM. Additionally, they were instructed to only use toolmark information present from the breechface and aperture shear.
  - Each examiner was provided an answer sheet to record their results from VCM analysis.
    - VCM result choices: Identification, Inconclusive, and Elimination
  - A proctor was present to administer the answer sheet and provide guidance on software functions. When the examiner completed a VCM test, they returned their answer sheet to the proctor before proceed to the next VCM test.
- Examiner VCM Test sheets were compiled.

Phase I - Completion Date: November, 2016

Phase II - Assessment of Consecutively Manufactured Slides
Start Date: April, 2016

The Association of Firearm and Tool Mark Examiners (AFTE) Theory of Identification outlines the elements necessary for an examiner to conclude common source fortoolmark identification, the following element expresses what is necessary when evaluating individual characteristics for common source:

- Agreement is significant when the agreement in individual characteristics exceeds the best agreement demonstrated between toolmarks known to have been produced by different tools (KNM) and is consistent with agreement demonstrated by toolmarks known to have been produced by the same tool (KM).
- The statement that "sufficient agreement" exists between two toolmarks means that the agreement of individual characteristics is of a quantity and quality that the likelihood another tool could have made the mark is so remote as to be considered a practical impossibility.[1]
- This element of the AFTE Theory articulates the importance of "significant" agreement when the quality and quantity of agreement of the individual characteristics (similarity) exceeds the

[1]Association of Firearm and Tool Mark Examiners (AFTE) Journal, July 1992, Vol. 24, No. 3 and Fall 2011, Vol. 43, No. 4.

agreement encountered in a "Best Known Non-Match" (BKNM) comparison. Previously published validation studies, using LCM, contained test samples utilizing consecutively manufactured barrels or slides. Using consecutively manufactured items produces test samples with a high degree of similarity of individual characteristics from different known sources – BKNM "worst case scenario". For Phase II, the following method was used to validate VCM using "Best Known Non-Match" test samples:

- Consecutively manufactured slides Redacted were test fired for physical sample.
- Each test and test sample was given a unique identifier.
    - Test samples and gel were prepared for entry/use.
    - Cartridge cases were scanned using Cadre TopMatch-GS 3D instrument.
- Software used for VCM allowed for one-to-one virtual comparison.
    - Each examiner was provided an answer sheet to record their results from VCM analysis.
        - VCM result choices: Identification, Inconclusive, and Elimination
    - A proctor was present to administer the answer sheet and provide guidance on software functions. When the examiner completed a VCM test they returned their answer sheet before proceeding to the next VCM test.
    - One BKNM (VT #11) test design had no matching pairs, the purpose of this test design was to determine if a false positive result would be recorded when test samples had consistent class characteristics and high degree of similarity with individual characteristics using VCM.
- Examiner VCM Test sheets were compiled.

Phase II - Completion Date: November, 2016

Review of Validation Results with FBI Laboratory Senior-Level Scientists and Statistician Meeting Date: November, 2016

At the completion of Phase II VCM validation, the results and a demonstration of the Cadre TopMatch-GS 3D toolmark topographical instrument were given to the FBI Laboratory Senior-Level Scientists and Statistician. After reviewing the results, the Senior-Level Scientists and Statistician determined that an additional VCM analysis should be performed on previously examined casework results to assess its performance versus LCM.

Phase III - Assessment of Previously Examined Casework Results using VCM Start Date: November, 2016

Previously examined casework containing cartridge case analysis, using LCM, was reexamined using VCM. For Phase III, the following method was used to validate VCM using previously examined casework using LCM:

- Examiners were requested to identify completed casework involving cartridge case comparisons using LCM.

  - Evidence was assigned to a test proctor for custody of evidence and 3D scanning.
  - Each item of evidence was given a unique identifier different from the evidence identifier.
  - Samples and gel where prepared for entry/use.
- Ground Truth (GT) samples were produced using the FBI Laboratory Reference Firearms Collection (RFC).
  - GTs were given a unique identifier and prepared for scanning.
- Tests were assembled using evidence from one submission with a GT inserted.
  - Cartridge cases were scanned using Cadre TopMatch-GS 3D instrument.
- Software was designed to isolate a one-to-one VCM.
  - Each examiner was provided an answer sheet to record their results from VCM analysis.
    - VCM result choices: Identification, Inconclusive, and Elimination.
- Research proctor was present to administer answer sheet and provide guidance on software functions. When the examiner completed a VCM test they returned their answer sheet before proceeding to the next VCM test.
- Each test had a least one GT.
- Examiner VCM test sheets were compiled.

Phase III – Completion Date: January, 2017

Results of Validation for VCM

Proficiency Tests from Collaborative Testing Services from 2003 through 2014 were utilized to produce VCM validation tests for Phase I.

- There were a total of ten proficiency tests used for VCM validation.
- There were a total of five test participants – qualified examiners.
- A total of 921 Virtual Comparisons were conducted.
  - No False Positives were reported using VCM. There were no reported False Positives recorded by the FTU from the original proficiency test distribution using LCM.
  - One recorded False Elimination using VCM. There were no reported False Eliminations recorded by the FTU from the original proficiency test distribution using LCM.
    - Root cause for False Elimination was conducted for Validation Test (VT) #4, Item A- Item D comparison. Evaluation of the Item A scan determined that partial reconstruction of the firing pin impression had occurred and was used as the source for elimination. The current version of Cadre TopMatch-GS 3D does not provide scanned information for the firing pin impression due to the gel's inability to make contact with the firing pin impression.
    - Examiners were reminded not to consider the firing pin impression for toolmark VCM.
    - VT #4 was reassembled with different unique identifiers and reissued for VCM.
      - No False Elimination was recorded for reissued VT #4

- Slides from consecutively manufactured 9mm Luger Smith & Wesson pistols, Model M&P were utilized to produce VCM validation test samples for Phase II.
- There were three tests designed using consecutively manufactured slides
- There were a total of five test participants – qualified examiners.
- A total of 675 virtual comparisons were conducted with no False Positives or False Negatives
    - VT #11 had no matching pair with consistent class characteristics for all samples, all inconclusive results were recorded.
    - VT # 12 had 3 true identifications with consistent class characteristics for all samples, a total of 15 IDs were possible, 8 IDs and 7 inconclusive results were recorded.
    - VT #13 had 7 true identifications with consistent class characteristics for all samples, a total of 35 IDs were possible, 24 IDs and 11 inconclusive results were recorded.
- Previously examined/reported firearm cartridge cases examinations using LCM were utilized to produce VCM validation tests for Phase III.
- A total of eight cases were selected for reexamination using VCM
- Seven tests had four participants and one test had five participants
- A total 946 virtual comparisons were conducted with no False Negatives or False Positives with GT.
    - VT #14 - LCM results, the Item 1 pistol was identified to the Item 2 cartridge case, there were 10 inter-comparisons with a total of 30 IDs, 29 IDs and 1 inconclusive result were recorded. There were a total of 20 GT eliminations, 11 eliminations and 9 inconclusive results recorded using VCM.
    - VT #15 - LCM results, the Item 1 was identified to the Item 2 through Item 5 cartridge cases, there were 28 inter-comparisons with a total of 112 IDs, 112 IDs results were recorded using VCM. There were a total of 32 GT eliminations, 24 eliminations and 8 inconclusive results recorded using VCM.
    - VT #16 - LCM results, the Item 21 pistol was identified to the Item 23 cartridge case. There were a total of 6 inter-comparisons with 24 IDs, 22 IDs and 2 inconclusive results recorded using VCM. There were a total of 16 GT eliminations, 5 eliminations and 11 inconclusive results were recorded using VCM.
    - VT #17- LCM results, the Item 7 pistol was identified to the Item 3 through Item 5 cartridge cases. There were a total of 21 inter-comparisons with 64 IDs, 64 ID results recorded using VCM. There were a total of 28 GT eliminations, 21 eliminations and 7 inconclusive results recorded using VCM.
    - VT #18- LCM results, the Item 1 through Item 5 cartridge case were identified as having been fired from the same pistol. There were two groups of inter-comparisons (identifications) with a total of 52 IDs, 51 IDs and 1 inconclusive results reported using VCM. There were a total of 12 GT identifications, 12 IDs reported using VCM. There were a total of 40 GT eliminations, 32 eliminations and 8 inconclusive results recorded using VCM.
    - VT #19 - LCM results, the Item 1 pistol was identified to the Item 3 through Item 11, and Item 18 cartridge cases. There were a total of 66 inter-comparisons with 264 IDs, 230 IDs and 34 inconclusive results recorded using VCM. There were a total of 48 GT eliminations, 30 eliminations and 18 inconclusive results recorded using VCM.
    - VT #20 - LCM results, the Item 4 pistol was inconclusive with the Item 6 and Item 7 cartridge cases, and the Item 6 and Item 7 cartridge case were identified has having

been fired from the same pistol. There were 15 inter-comparisons with a total of 60 IDs, 7 IDs and 43 inconclusive results recorded using VCM. There were a total of 24 GT eliminations, 0 eliminations and 24 inconclusive results recorded using VCM.

- VT #21- LCM results, Item 3 pistol was identified as having fired the Item 1 and Item 2 cartridge cases. There were 10 inter-comparisons with a total of 40 IDs, 20 IDs and 20 inconclusive results recorded using VCM. There were a total of 20 GT eliminations, 15 eliminations and 5 inconclusive results recorded using VCM.

Limitations

When using Cadre TopMatch-GS 3D scanning instrument for VCM, the following is a list of limitations:

- If gel cannot make contact with the toolmark, digital reproduction is not possible.
- Currently, Cadre TopMatch-GS 3D only provides digital reproduction of the breechface, firing pin aperture, and firing pin aperture shear toolmarks.
  - Chamber marks and firing pin impression are not part of the digital reproduction, which can be used for analysis when determining common source.
  - Extractor and ejector toolmarks are not part of the digital reproduction, which can be used for analysis when determining common source for loading and extraction.
  - Cadre TopMatch-GS 3D cannot scan bullets at this time.
- The performance properties and handling of the gel used to render the 3D topographical scan of a toolmark are critical for image acquisition and digital reproduction. This can be impacted by:
  - Contaminates and/or debris, on the surface of the gel, can be constructed along with the scanned toolmark surface.
  - Improper lamination of iron oxide layer on gel – cracks, inconsistency/density for iron oxide layer application.
  - The gel has a finite use and needs to be retired once exhausted. This can include:
    - Approximately thirty scans with a single piece of gel.
    - Tears within membrane of the gel.
- The 3D toolmark scan produced by Cadre TopMatch-GS 3D creates scans that are consistent in color.
  - Examiner cannot determine the metallic properties of the scanned images due to the consistent color of the 3D toolmark scans.

Critical Aspects and Conditions for Reliable Results for VCM

To achieve reliable results using the Cadre TopMatch-GS 3D instrument, the following must be performed to produce accurate 3D toolmark scans for VCM:

- Produce unique identifiers for each piece of gel used for 3D toolmark scans
  - Record the manufacturer's production lot information

- Perform calibration check (performance) for each piece of gel used for 3D toolmark scans
    - Maintain results of the gel performance check
    - If gel fails performance check, record results and remove from use
- Perform proper cleaning techniques when using gel
- Perform inspection of gel for proper lamination of reflective layer
- Perform scan of Standard Reference Material (SRM) 2461-118 (Cartridge Case) before scan acquisition for evidence and at the end of the work day.
    - Maintain results of SRM scans
- Perform proper cleaning technique for evidence prior to scan acquisition
- Proper cataloging of class characteristics for scan data file
- Proper scan image selection by examiner when performing VCM

Accuracy

Following traditional comparison methods integrated with digital reproductions of toolmarks, the validation method (plan) demonstrated that 3D toolmark comparison for common source determination using VCM is as accurate and in some cases better than traditional LCM. This level of performance is achieved, due to the reduction of interfering specular reflectance (bright spots) with an increased level of microscopic detail from scanned toolmark reproductions.

Competency Testing

The Technical Leader, Physical Scientist/Forensic Examiners (PSFE), and Physical Scientist/Non Examiner (PSNE) are recognized as having passed the competency testing for using Cadre TopMatch-GS 3D. The following individuals that participated in the validation of Cadre TopMatch-GS 3D are recognized as being competent and qualified to use this instrument for VCM:

Redacted

Redacted

Records

Records regarding the validation and competency testing of VCM using Cadre TopMatch-GS 3D will be retained in the FTU.