QUANTUM
3D MICROSCOPE

QUANTUM 3D MICROSCOPE – A BENCHMARK STUDY

THE DIFFERENCES OF WORKING A CASE USING 3D MICROSCOPY VERSUS CONVENTIONAL COMPARISON MICROSCOPY

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Overview

- This benchmark study involved the use of 3D microscopy to analyze a forensic firearm case, and examined the differences with conventional comparison microscopy.
- The case contained 24 bullets fired from Ruger brand firearms using 9 mm Luger ammunition.
- The work was performed independently by two seasoned forensic firearm examiners. Each of them analyzed the 24 bullets, first using a conventional comparison microscope, and then repeating the examination using a 3D microscope.

Highlights

- Using the Quantum 3D Microscope™ to analyze the 24 bullets yielded a 9x to 10x time saving compared to the use of a conventional comparison microscope.
- The superior quality of images produced by the Quantum 3D Microscope enhanced the confidence of common source determinations and alleviated some of the concerns for potential bias during the analysis work.
- The Quantum 3D Microscope improved the reliability of the common source determinations by providing scientifically defensible false match rates associated with the results obtained.
- In line with the AFTE Theory of Identification and Range of Conclusions, the RBL diagram of the Quantum 3D Microscope helped the examiners graphically establish clear distinctions between non-matching and matching conditions of the analyzed bullets.

[1] *http://creativecommons.org/licenses/by-nc-nd/4.0*

1. INTRODUCTION

The purpose of this study was to compare how 3D microscopy can be applied to a forensic firearm case workflow, and to establish the differences when using a conventional comparison microscopy. More specifically, the Quantum 3D Microscope™ was used with a case involving 24 bullets fired from multiple firearms, including two known firearms.

The Quantum 3D Microscope

Quantum 3D Microscope (Q3M) **(Figure 1)** was first introduced in May 2020 by Forensic Technology. The Q3M is a workstation that allows the capture of marks on small objects, such as bullets, with surfaces having cylindrical, flat, and wavy shapes. While this typically involves bullets, it may include toolmarks such as those produced by the firearm chamber on the sides of fired cartridge cases. Accurate measurements of these toolmarks are assured as Q3M is calibrated using ISO 17025 certified reference targets.

Figure 1: Quantum 3D Microscope by Forensic Technology

In addition to measuring and capturing toolmarks on object surfaces, quantitative analysis can be performed to establish the False Match Rate (FMR) between two bullets. The FMR calculation is based on two different scores: the pattern matching score and the line counting score. These scores are plotted on a RBL Graph **(Figure 2)**. The pattern matching score (PMS) is represented horizontally and the line counting score (LCS) is represented vertically. The FMR is determined from the placement of these two scores within the graph. The FMR for a given similarity score represents the probability that two bullets that were not fired by the same firearm would generate a higher similarity score.

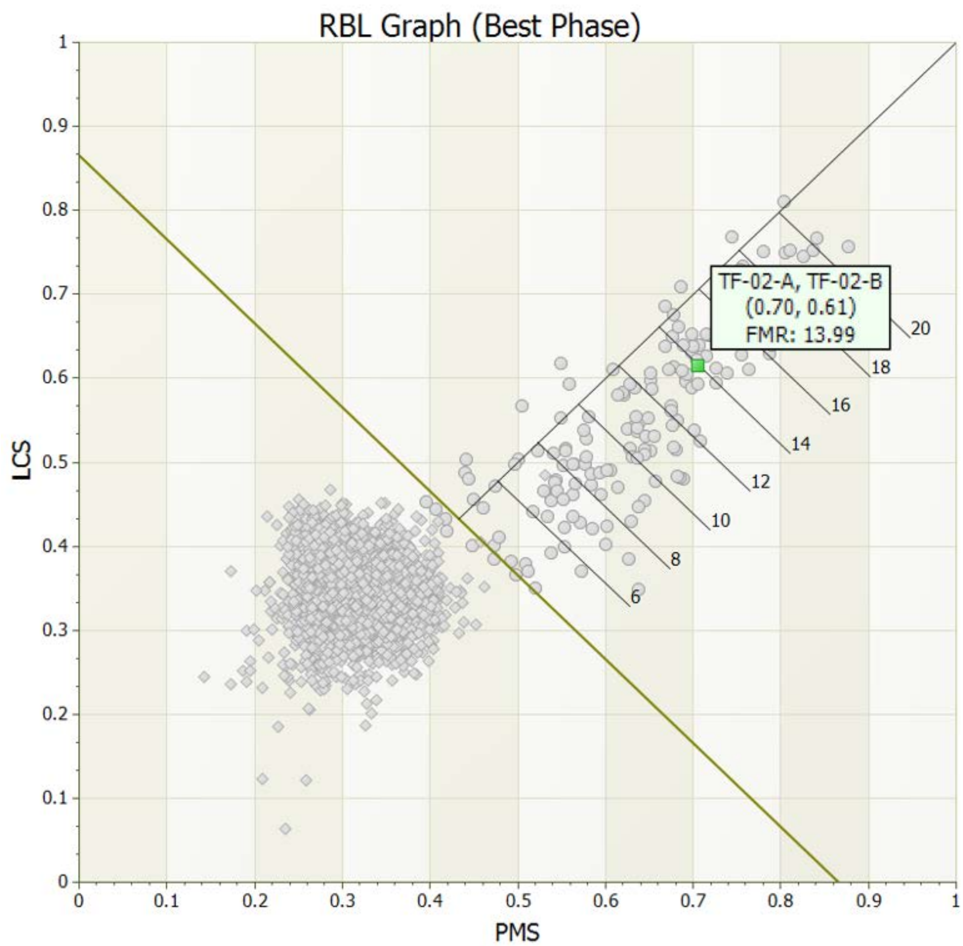


Figure 2: Representative RBL Graph showing FMR Index of 13.99 for TF-02-A and TF-02-B

Q3M has been discussed in previously published articles and webinars[2] including:

- Roberge, D., Beauchamp, A., Levesque, S., 2019. Objective identification of bullet based on 3D pattern matching and line counting scores. *International Journal of Pattern Recognition and Artificial Intelligence 33(11) DOI: 10.1142.*
- Quantum 3D Microscope - What to Expect from the Arrival of the Quantum 3D Microscope. *White Paper, Forensic Technology (2020).*
- Quantum 3D Microscope - Introducing a game changer for firearm and toolmark examiners. *Webinar, Forensic Technology (May 2020).*
- Multi-Caliber Quantitative Analysis. *Webinar, Forensic Technology (December 2020*).

[2] Published articles and webinars available at www.ultra-forensictechnology.com/en/quantum.

The Approach

This study involved 24 bullets were acquired using a Q3M Workspace labeled FT_Trial_Set-01. Their relationship was that some of them were from known firearms while others were unknowns. The goal was to emulate evidence that could have been recovered from a crime scene, or related criminal cases involving firearms.

All bullets were fired by Ruger brand firearms, using 9 mm Luger ammunition of various brands, and had six lands and grooves with a right twist and with similar dimensions. All test fired bullets were supplied by the Allegheny County Crime Laboratory. Bullet acquisitions into the Q3M took approximately 4.5 hours to complete. Figure 3 shows the mounting of the bullet prior to acquisition.

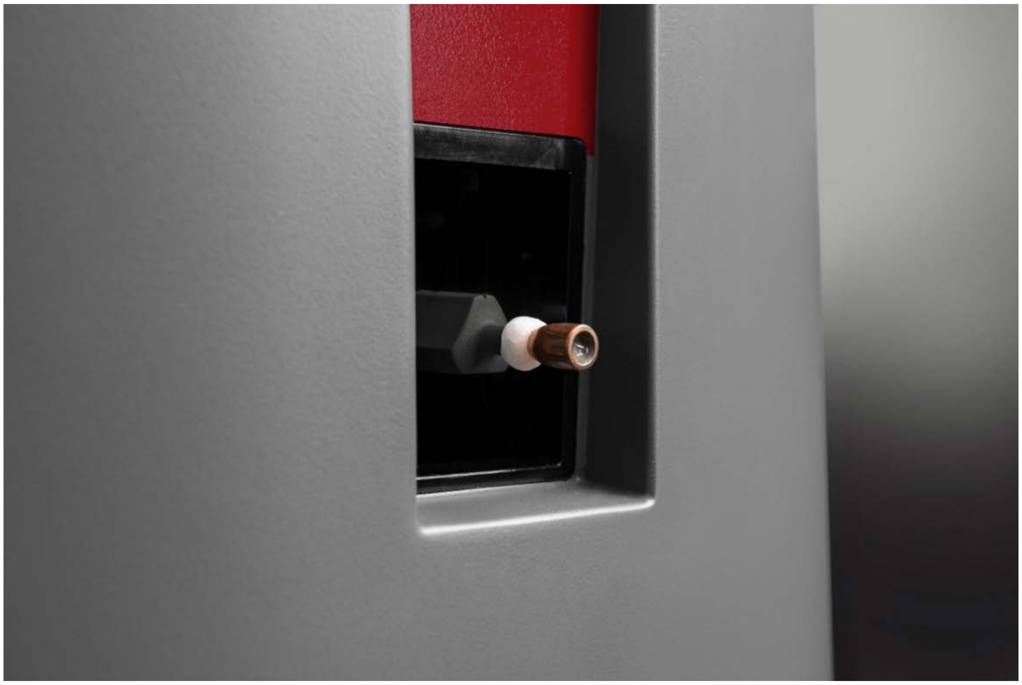


Figure 3: Bullet mounted prior to acquisition into the Q3M

The bullets were imaged into Q3M in the following numerical sequence:

Firearm 1	Firearm 2	Unknowns
TF-01-A TF-01-B	TF-02-A TF-02-B	UNK-01 through UNK-20

The bullets were then sorted into individual bags for conventional comparison microscope (CCM) examinations and given the following alphabetical naming sequence:

Firearm 1	Firearm 2	Unknowns
TF-01-A TF-01-B	TF-02-A TF-02-B	UNK-A through UNK-T

Different matching keys were used for the Q3M and CCM tests. The alphabetical designations were randomly assigned to the 20 unknown bullets, so they were not assigned in the same sequence as UNK-01 to UNK-20.

However, it is important to note that the CCM results in this study are presented using their numerical equivalent instead of their letter designations. This conversion is useful to have a correspondence with the Q3M results, and it also allows the key to the letter designations to remain hidden for future participants desiring to complete a similar study reusing these bullets.

The physical bullets were sent to two firearm examiners, Mr. Ron Nichols, and Mr. Paul Murphy, along with a USB flash drive containing the FT_Trial_Set-01 workspace. Instructions were to compare the 24 bullets using conventional comparison microscopy as though they were bullets submitted in a typical case. Once completed, the 24 bullets were to be compared using Q3M. The different designations prevented knowledge from the conventional comparison microscope to be used when performing the comparisons using the Q3M.

The examiners' experiences and available conventional comparison microscopes were slightly different. Therefore, the study results of each examiner will be presented separately in the next sections.

About the Authors

Ron Nichols

Forensic Firearms Examiner, Instructor and Consultant

Ron began his forensic science career in 1984 with the Contra Costa County Sheriff-Coroner laboratory in Northern California. After five years performing casework in drug identification as well as forensic toxicology Ron accepted a position with Oakland Police Department, serving as a Criminalist until 2000. While with Oakland he began his career specialty as a firearm and toolmark examiner. In 2001, he was hired as a firearm and toolmark examiner with the Bureau of Alcohol, Tobacco, Firearms and Explosive (ATF). He served in the Western Regional Laboratory for approximately 12 years before transferring to Field Operations where he served to help the reboot of the NIBIN program nationwide including the development of the NIBIN National Correlation and Training Center. Ron took early retirement in 2017 to establish a consulting and training firm. Since then, his primary focus has been on case consultation along with the development and implementation of training for current and new firearm examiners. Ron has published two books (*Firearm and Toolmark Identification: The Scientific Reliability of the Forensic Science Discipline, and Developing a Preventive Crime Gun Strategy: A Playbook for Success*). Ron also has four different book contributions and has published 17 articles in scientific journals. The bulk of his work has focused on understanding the scientific foundations of the firearm and toolmark discipline.

Paul Murphy

Senior Firearms Technical Advisor and Forensic Firearms Examiner

Paul J. Murphy currently acts as Forensic Technology's Senior Firearms Technical Advisor and Subject Matter expert. Paul has been in this role since 2005. Prior to this, Paul has been a Forensic Firearm Examiner since 1984. He served in the South African Police service for 22 years where he was trained as a Forensic Firearm Examiner by the South African Police Forensic Science Laboratory. During this period, Paul held the position of Commanding Officer of the South African Police Service Eastern Cape Forensic Science Laboratory, with the rank of Colonel until his resignation in 1999. Paul then move to the United States and worked as a Senior Forensic Scientist for the Virginia DFS until 2005. Paul cumulated 36 years of experience as a Forensic Firearm Examiner, and he is a Distinguished Member of the Association of Firearm and Tool Mark Examiners (AFTE).

Andrew Boyle

Firearms Forensic Specialist

During Andrew's 30 years with Forensic Technology, he has held positions as an IBIS Instructor, Firearm Researcher and Subject Matter Expert for the Research & Prototyping Group. In the last 9 years, one of Andrew's roles has been to act as the liaison for the INTERPOL Ballistics Information Network (IBIN) program. Working in collaboration with INTERPOL, Andrew has travelled the world promoting the benefits of IBIS and the IBIN program to forensic firearm experts and government officials. Andrew currently works in the Marketing department and is responsible for trials and demonstrations of IBIS products and the Quantum 3D Microscope. Andrew designed and coordinated this benchmark study.

Michel Paradis

Senior Product Manager

After graduating from the University of Sherbrooke, in Canada, with a degree in Electrical Engineering, Michel started his career as a software designer in the telecommunications industry. He joined Forensic Technology in 2003 to lead the IBIS BRASSTRAX software development until 2006 when he became the product manager responsible for the Integrated Ballistic Identification System (IBIS). As part of the Marketing team, he is now responsible for the evolution of IBIS and the Quantum 3D Microscope.

About LeadsOnline

LeadsOnline (www.LeadsOnline.com), founded in 2000, is dedicated to supporting U.S. law enforcement by providing innovative data, intelligence, and SaaS solutions for criminal investigations, primarily focusing on property crimes. Over the years, LeadsOnline (LO) has become a trusted partner for agencies nationwide. To enhance public safety and expand its capabilities, LO acquired Forensic Technology (FT) a year ago. FT, a 30-year-old Canadian company, is renowned for its cutting-edge ballistic identification solutions and global presence. This strategic merger has empowered LO to serve agencies in over 80 countries, significantly improving the efficiency of solving gun crimes.

Today, LeadsOnline offers a comprehensive Solution Portfolio designed to empower law enforcement agencies globally in advancing their cases more swiftly. This portfolio includes two distinct sets of solutions: Intel Solutions and Ballistic Solutions, both of which play crucial roles in expediting case resolutions and enhancing community safety efforts.

Intel Solutions: Our Intel Solutions focus on providing data, technology, and intelligence tools to law enforcement agencies, both in the U.S. and internationally. These solutions enable investigators to uncover critical insights, identify suspects, locate stolen property, and detect patterns in criminal activities. From real-time crime monitoring to mobile device analysis, our Intel Solutions are pivotal in solving a wide range of crimes, including gun-related offenses, violent crimes, missing persons cases, and property crimes.

Ballistic Solutions: Our Ballistic Solutions (formerly Forensic Technology) specialize in advanced 3D imaging and analysis tools tailored for processing evidence from gun crimes. Leveraging state-of-the-art technology, these solutions allow law enforcement agencies to generate timely investigative leads, identify firearm-related crimes, and enhance overall community safety. From network-based ballistic identification to cutting-edge 3D microscopy, our Ballistic Solutions provide essential support for gun crime investigations, forensic examinations, and common source determinations.

Forensic Technology, now a vital part of LeadsOnline, pioneered automated ballistic identification and analysis over three decades ago and continues to lead in forensic ballistics and firearm identification technologies that promote a safer society. In 1991, FT introduced the Integrated Ballistic Identification System (**IBIS**®), capable of suggesting possible matches between spent bullets and cartridge cases at speeds far beyond human capacity. This innovation helps forensic experts provide detectives with timely information about crimes, guns, and suspects.

Our ballistic identification solutions assist law enforcement and security agencies in more than 80 countries in solving gun crimes and ultimately reduce firearm violence. The ATF’s National Integrated Ballistic Information Network (NIBIN) program is powered by our IBIS technology, and we have supported and expanded the IBIS equipment deployed by ATF since 1994. Our long-standing partnership with ATF aims to reduce firearm-related crime in the United States.

Headquartered in Plano, Texas, with its Ballistics Centre of Excellence in Montreal, Canada, **LeadsOnline** operates offices in the USA, Ireland, Thailand, South Africa, and Mexico, employing over 300 professionals worldwide. Our mission is to "**empower law enforcement with the tools and data they need to advance cases faster."**

2. STUDY RESULTS – RON NICHOLS

Conventional Comparison Microscopy

Equipment. The initial comparisons were conducted using a VisionX equipped with objectives capable of the following magnifications – 6x, 10.8x, 19.4x, 32x, 57.6x, and 104x **(Figure 4)**. Available lighting included LED ring lighting with the ability to be adjusted in quarters, spot lighting, and shadow-free lighting. For this study's comparisons, shadowfree lighting was used. Photomicrographs of comparisons were taken using a 10MP USB-CMOS camera.

Figure 4: VisionX Conventional Comparison Microscope

Strategy. Considering that the bullets were to be handled as a typical case submission, the first step was to assess the class characteristics of the bullets to determine if any could be distinguished based on differences in class characteristics. The next step was to compare the test fired bullet pairs against each other to check for reproducibility. The last step was to determine which of the 20 unknowns were fired by the known firearms represented by the submitted test fired bullets. First, each of the unknowns A through T were compared with TF-01 test fires, then TF-02 test fires were compared with Unknowns A through T minus those identified to TF-01.

When comparisons to the known test fires were completed, the bullets identified to TF- 01 and TF-02 were removed, and a matrix was created to perform comparisons of the remaining bullets. Note that this methodical and deliberate comparison strategy was necessary to ensure the best results. The fact that all 20 unknowns had similar class characteristics greatly complicated the process as none could be eliminated based on class characteristics alone.

Results. When comparing TF-01 with the 20 unknowns, two unknowns, 3 and 9, were determined to have been fired from the same source. Only FT-01-A was used, after strong reproducibility was established with FT-01-B, so this initial work involved a total of 20 comparisons, 18 of which were inconclusive. Figure 5 shows correspondence on three different land-engraved areas of TF-01-A and Unknown 3.

Figure 5: Three different land-engraved areas of TF-01-A and Unknown 3 using VisionX

When comparing TF-02-B with the remaining 18 knowns, two of them, 6 and 14, were determined to have been fired from the same source. Figure 6 shows correspondence on three different land-engraved areas of TF-02-B and Unknown 14. This work with TF- 02-B involved a total of 18 comparisons, 16 of which were inconclusive.

Figure 6: Three different land-engraved areas of TF-02-B and UNK-14 using VisionX

Having identified four bullets to the two sets of knowns, 16 bullets remained and needed to be compared with one another. A matrix such as the one below (Figure 7) was built to ensure that all relevant comparisons were performed.

1	v	2	4	5	7	8	10	11	12	13	15	16	17	18	19	20
	2	v	4	5	7	8	10	11	12	13	15	16	17	18	19	20
		4	v	5	7	8	10	11	12	13	15	16	17	18	19	20
			5	v	7	8	10	11	12	13	15	16	17	18	19	20
				7	v	8	10	11	12	13	15	16	17	18	19	20
					8	v	10	11	12	13	15	16	17	18	19	20
						10	v	11	12	13	15	16	17	18	19	20
							11	v	12	13	15	16	17	18	19	20
								12	v	13	15	16	17	18	19	20
									13	v	15	16	17	18	19	20
										15	v	16	17	18	19	20
											16	v	17	18	19	20
												17	v	18	19	20
													18	v	19	20
														19	v	20

Figure 7: Sample matrix of comparisons of unknowns

As unknowns were identified with one another, samples identified as being from the same firearm could be removed from the matrix to reduce the number of comparisons performed.

The results of the comparisons among the unknowns are listed below:

- Inferred Firearm A — Unknowns 4, 13, and 17
- Inferred Firearm B — Unknowns 5 and 20
- Inferred Firearm C — Unknowns 7, 11, 15, and 19
- Inconclusive — Unknowns 1, 2, 8, 10, 12, 16, and 18

Figure 8 and Figure 9 show correspondence for three different land-engraved areas of Unknowns 13 and 17, and of Unknowns 15 and 19, respectively.

Figure 8: Three different land-engraved areas of Unknowns 13 (left) and 17 (right) using VisionX

Figure 9: Three different land-engraved areas of Unknowns 15 (left) and 19 (right) using VisionX

Ideally, once a bullet was linked to another, it would be completely removed from the matrix resulting in 100 performed comparisons. However, because the bullets varied in design and the design difference could result in differences on how well-marked the bullets were, an additional 44 comparisons were performed to address this. Of the 144 comparisons, 138 were inconclusive. Inconclusive results required extensive comparison because every land-engraved area on one bullet had to be compared with every landengraved area on the second bullet. Approximately 80 hours were spent on the VisionX in making these comparisons.

Quantum 3D Microscope

Strategy. Given the power of the Q3M's quantitative analysis technology, the decision was made to target the comparisons to which initial attention should be directed. The 20 unknowns were compared against each other, and the results were sorted by the False Match Rate Index in the Best Phase results.

Acquisition Name 1	Acquisition Name 2	Best Phase PMS	Best Phase LCS	Best Phase FMR
UNK-03	UNK-09	0.82	0.73	19.20
UNK-06	UNK-14	0.78	0.70	17.40
UNK-07	UNK-15	0.63	0.54	10.71
UNK-13	UNK-17	0.58	0.49	8.66
UNK-04	UNK-17	0.51	0.50	7.23
UNK-07	UNK-19	0.52	0.45	6.15
UNK-04	UNK-13	0.47	0.48	5.97
UNK-05	UNK-20	0.39	0.50	4.69
UNK-07	UNK-11	0.49	0.38	4.33
UNK-11	UNK-15	0.49	0.39	4.32
UNK-11	UNK-19	0.44	0.42	3.84

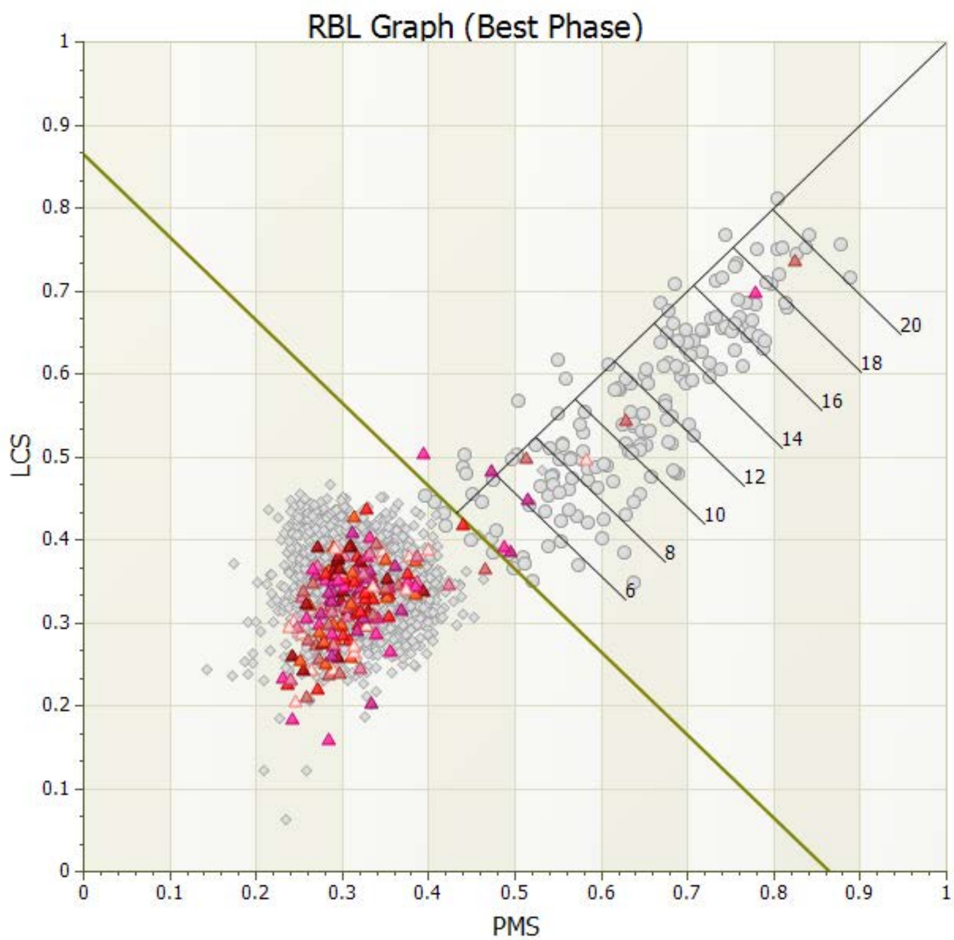


Figure 10: Tabulated results (partial) and RBL Graph for 20 Unknowns

The preferred strategy of examining and comparing all the unknowns and making all possible decisions regarding those unknowns prior to comparing with tests could be employed. Figure 10 shows an excerpt of the highest tabulated results and the RBL Graph of the 190 intercomparisons of the 20 unknowns.

Once those comparisons were assessed and evaluated, the next step was to perform the quantitative analysis of the test fires, TF-01 and TF-02. While this could be performed in a combined graph with the unknowns compared against each other, it was instead done separately to keep everything streamlined. For example, **Figure 11** shows the partial tabulated results with only the two unknowns sharing a common source with TF-01, and the RBL Graph for TF-01 against all the unknowns.

	Acquisition Name 1	Acquisition Name 2	Best Phase PMS	Best Phase LCS	Best Phase FMR
	UNK-09	TF-01-B	0.78	0.65	16.30
	UNK-03	TF-01-A	0.74	0.66	15.68
	UNK-03	TF-01-B	0.71	0.67	15.45
	UNK-09	TF-01-A	0.74	0.63	15.03

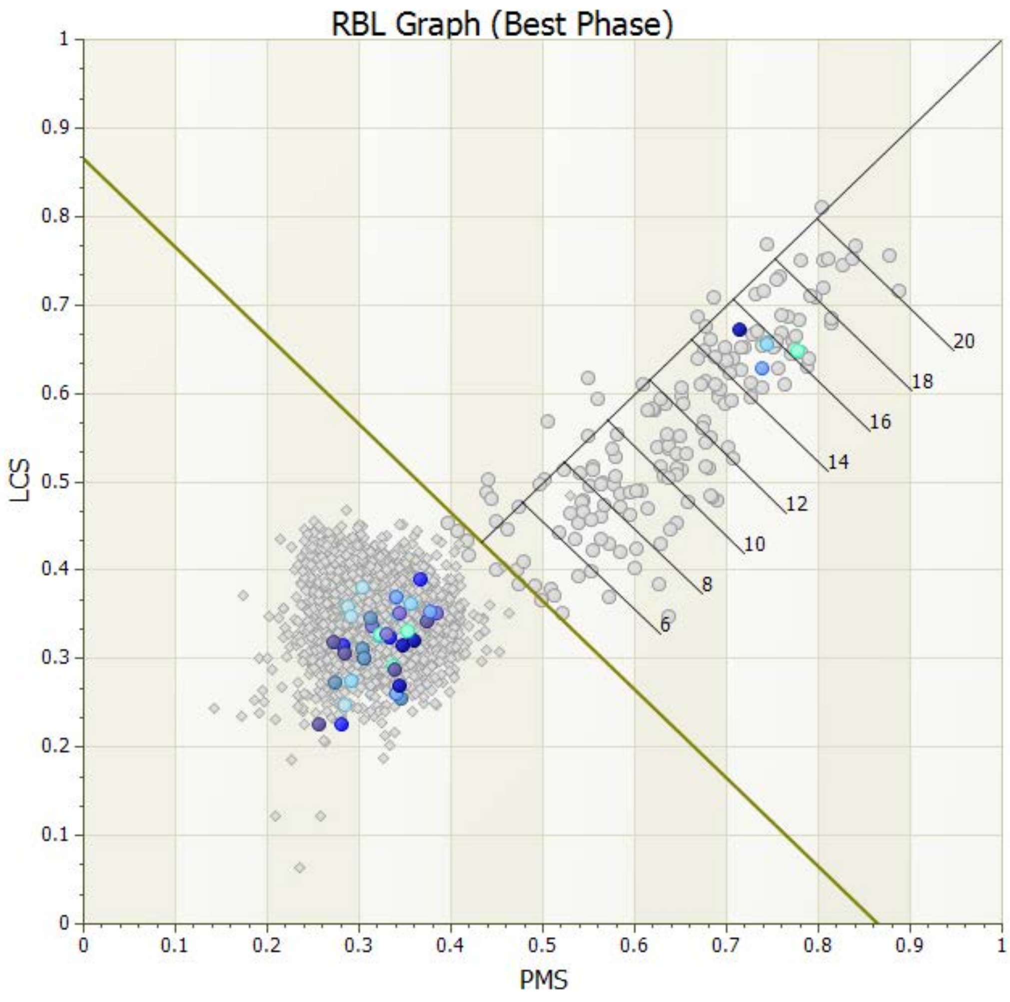


Figure 11: Tabulated results (partial) and RBL Graph for TF-01 vs. All Unknowns

Results. The results obtained using the Quantum 3D Microscope were the same as they were for conventional comparison microscopy. The same bullets were identified, and the same bullets had inconclusive results. What was significantly different was the total amount of time spent performing the comparisons and the comfort with which they were performed.

When comparing the unknowns among themselves, the 12 highest scoring results were confirmed within about one hour. The samples came up in the best "match" position and could be phased immediately. Once the phase position was verified, it was easier to scan the rest of the images to confirm that the two bullets showed sufficient correspondence to conclude they shared a common source. While this is possible on the comparison microscope, it does not happen often, and time must be taken to get the bullets into a phase position. **Figure 12** shows different land-engraved areas of UNK-04 and UNK-13.

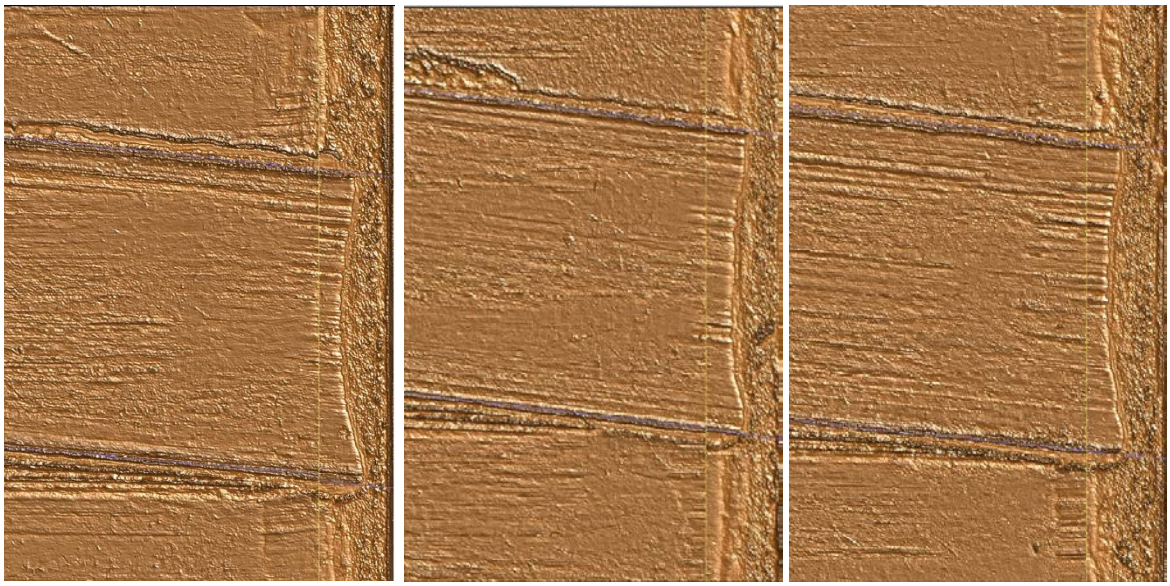


Figure 12: Three different land-engraved areas of UNK-04 (left) and UNK-13 (right) using Q3M

The pairs of bullets represented by the next 10 highest scores were assessed and compared. The time spent was approximately 26 hours and resulted in three same source conclusions and seven inconclusive results. Once completed, samples with a False Match Rate Index of less than 2 (FMR of 1 in 100) were compared. After several were examined, it was decided that further comparisons would add no further value. **Figure 13A**, **13B**, and **13C** illustrate the strength of various FMR Index values combined with the comparison viewing software showing one land-engraved area of the samples in their best match position.

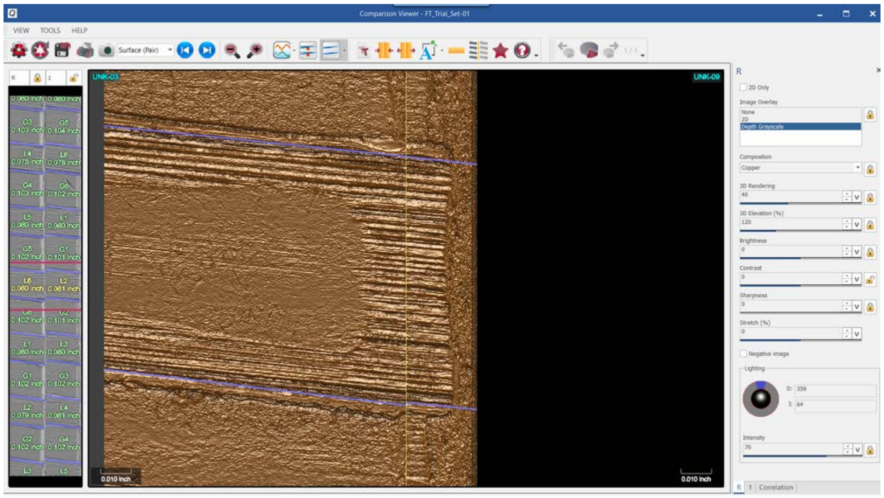


Figure 13A: Same Source at best match position, UNK-03 vs. UNK-09 — FMR Index: 19.20

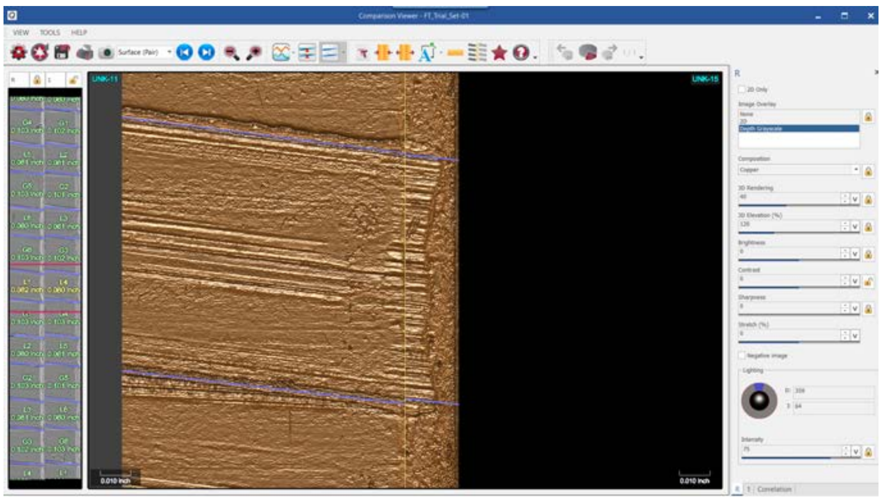


Figure 13B: Same Source at best match position, UNK-11 VS. UNK-15 — FMR Index: 4.32

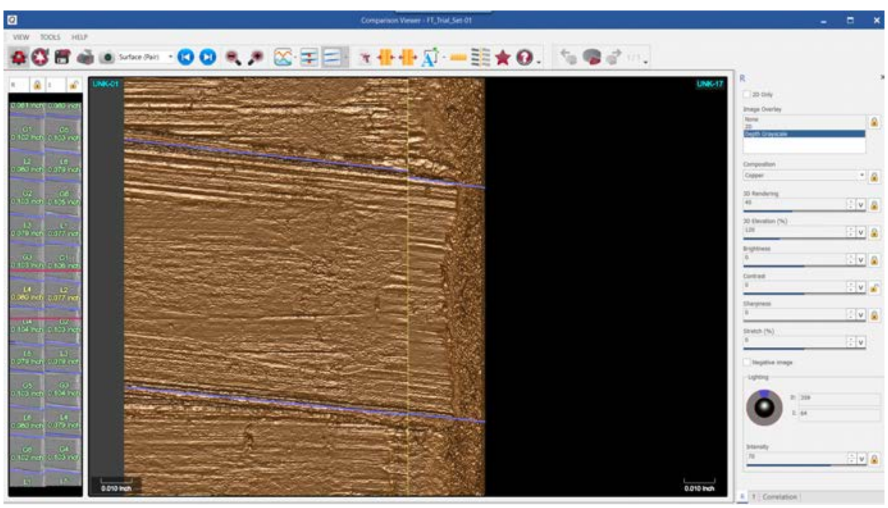


Figure 13C: Different Source at best match position, UNK-01 VS. UNK-17 — FMR Index: 1.85

Once the unknowns were evaluated, they were compared with the known test fires. The unknowns associated with each of those pairs of tests had a significantly higher FMR Index and, when assessed and compared, were easily confirmed. In total, approximately 4 hours were spent performing the comparisons on the Quantum 3D Microscope. Figure 14 and Figure 15 show correspondence between TF-01-A vs. UNK-03 and TF-02-B vs. UNK-14, respectively.

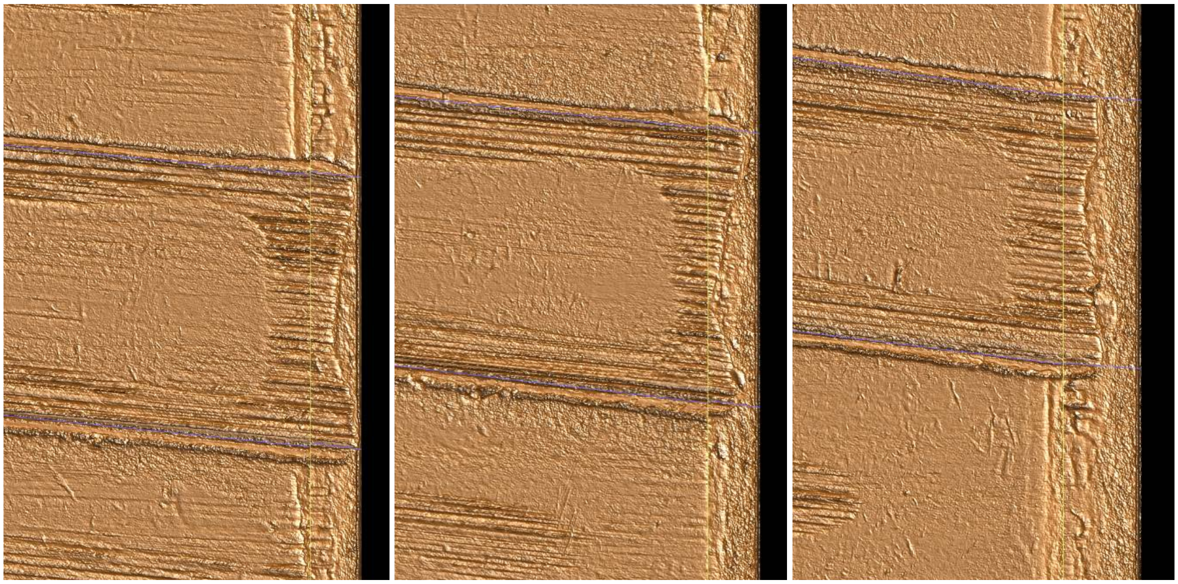


Figure 14: Three different land-engraved areas of UNK-03 (left) and TF-01-A (right) using Q3M – FMR Index: 15.68

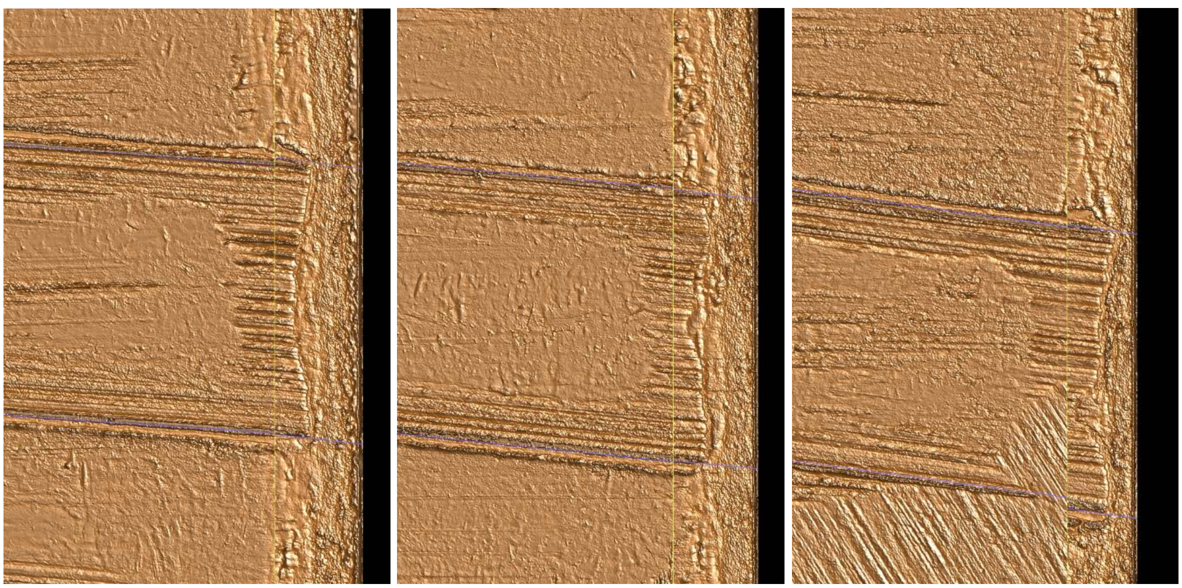


Figure 15: Three different land-engraved areas of UNK-14 (left) and TF-02-B (right) using Q3M – FMR Index: 17.91

3. STUDY RESULTS – PAUL MURPHY

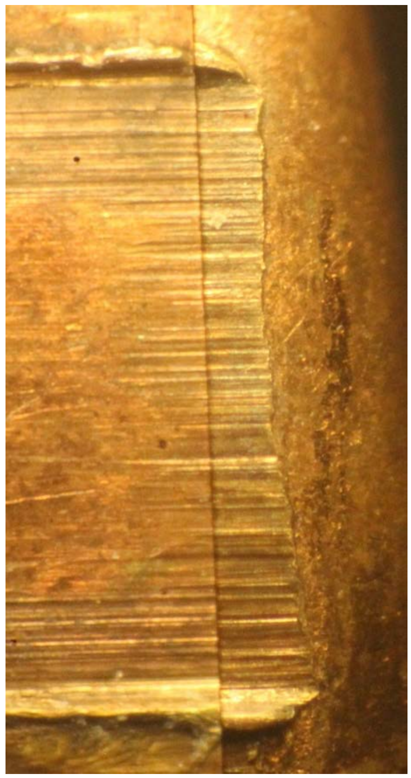
Conventional Comparison Microscopy

Equipment. The comparison work was conducted using a Leica UFM4 comparison microscope equipped with fluorescent illumination and a Canon 60D DSLR camera mounted with a phototube **(Figure 16)**.

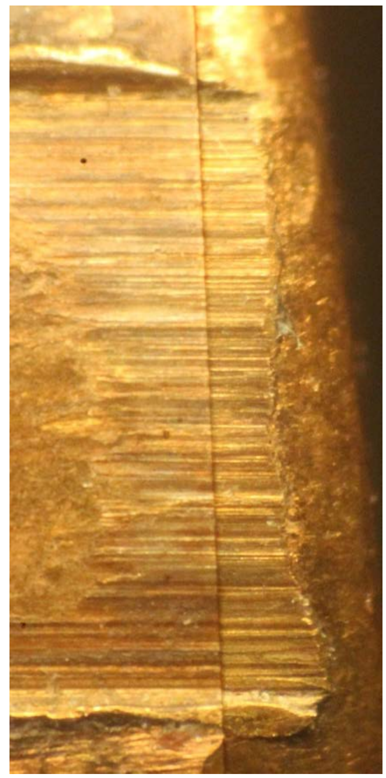
Figure 16: Leica UFM4 Conventional Comparison Microscope (CCM)

Strategy. Treating the trial bullets as a typical forensic firearms case submitted to a forensic laboratory involved a series of steps. Firstly, a basic triage and examination of the bullets was performed to determine caliber and class characteristics. The second step was to microscopically intercompare the submitted test fires TF-01-A/B and TF-02- A/B to determine reproducibility. The third step was to determine which of the unknown bullets were fired by the same firearm that fired TF-01 and TF-02 pairs of submitted test fired bullets. The fourth step was to examine the unknown bullets that were excluded as having been fired by TF-01 and TF-02 to determine from how many firearms they were fired. Since all the submitted unknowns and test fired bullets were of the same caliber and had similar general rifling class characteristics, the last step was complicated and time consuming.

Results. Comparison of the 20 unknown bullets to the TF-01 test fired bullets resulted in 2 of the 20 unknowns identified as having been fired by the TF-01 firearm. Comparison of the remaining 18 unknown bullets to the TF-02 test fired bullets resulted in 2 of the remaining 18 unknown identified as having been fired by the TF-02 firearm. Figure 17 shows correspondence from comparisons of unknowns versus TF-01 and TF-02.



Tf-01-b vs. Unknown 9



TF-02-B vs. Unknown 14

Figure 17: Comparisons of test fires with unknowns using Leica UFM4 CCM

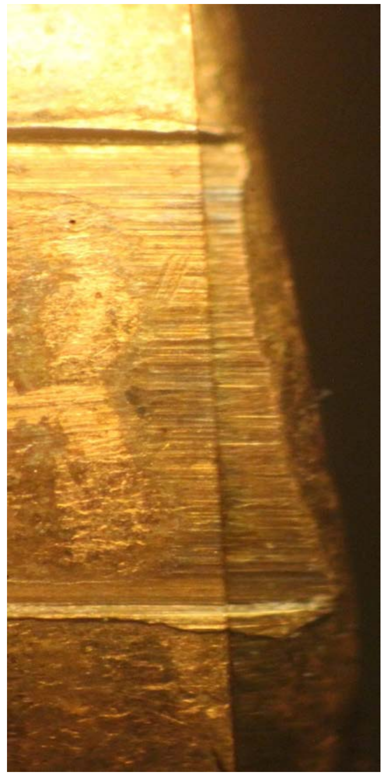
Intercomparison of the remaining 16 unknown bullets resulted in the following:

- A group of 3 unknown bullets were identified as having been fired by same firearm and another (1) unknown was determined to be inconclusive as to having been fired by the same firearm as this group. An example of the correspondence between two of the three bullets identified in this group is show in Figure 18.

- Another group of 3 unknown bullets were determined to be inconclusive as to having been fired by the same firearm.

- Another group of 2 unknown bullets were determined to be inconclusive as to having been fired by the same firearm.

Approximately 60 hours were spent performing all the comparisons on the Leica microscope.



Unknown 15 vs. Unknown 19

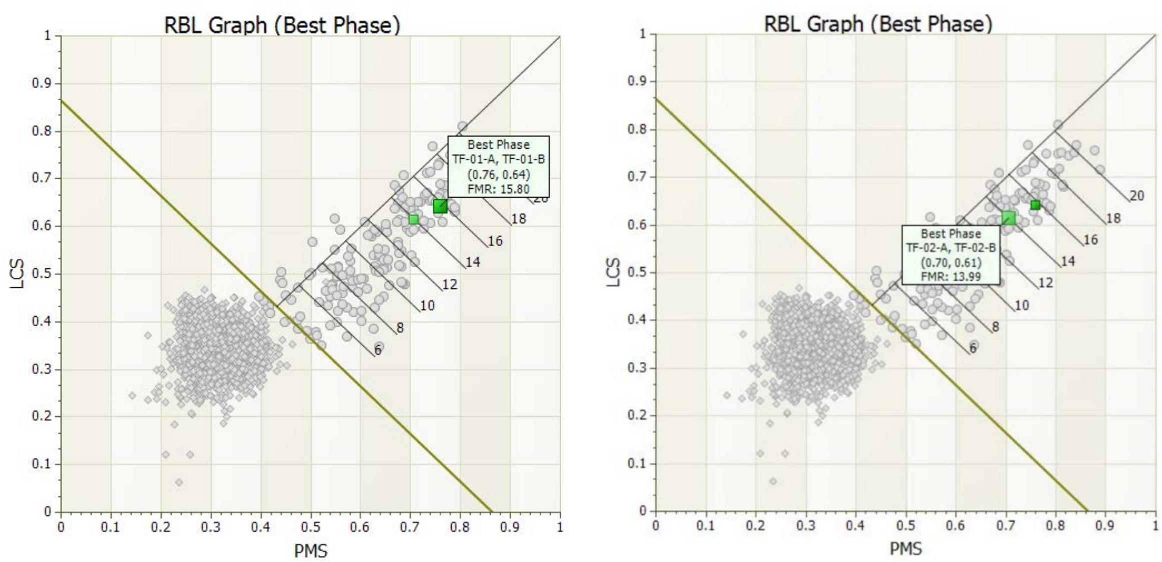
Figure 18: Correspondence of two unknowns identified as having been fired by the same firearm

Quantum 3D Microscope

Strategy. The approach for performing the comparisons on the Quantum 3D Microscope was similar to the strategy used for performing comparisons using conventional comparison microscopy, namely:

1. Intercompare the TF-01 and TF-02 test fired bullet pairs to determine reproducibility.
2. Compare the TF-01 and TF-02 test fired bullet pairs with the unknowns by means of quantitative analysis to determine which bullets should be examined visually with the comparison viewer:
    a. Test fired pair 01 with 20 Unknowns.
    b. Test fired pair 02 with 20 Unknowns.
3. Compare the remaining unknowns (not linked to TF-01 and TF-02) by means of quantitative analysis to determine which groups of unknowns should be visually examined with the comparison viewer to determine common source.

Results. The results obtained by the Quantum 3D Microscope were more definitive than the results obtained using conventional comparison microscopy. Step 1, which was to intercompare the test fires within each pair to determine their reproducibility, was done using quantitative analysis, and each pair demonstrated a high FMR Index. Figure 19 shows the RBL graph with the values for each of the test fire pairs.

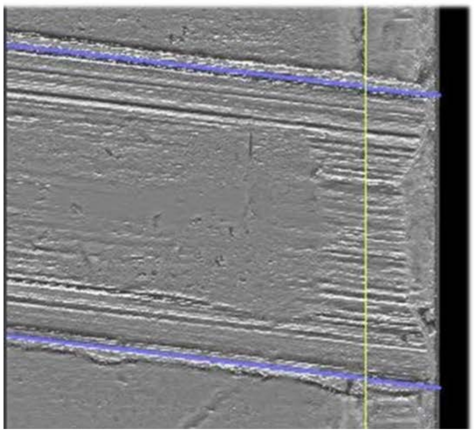


TF-01-A vs. TF-01-B *TF-02-A vs. TF-02-B*

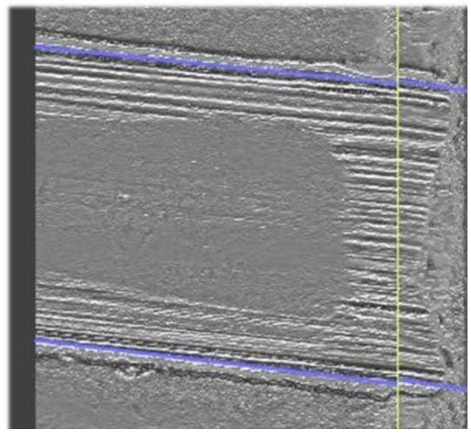
Figure 19: RBL Graphs of test fire pairs using Q3M

For Step 2a, the TF-01 test fires were compared with the 20 unknowns, it was determined that UNK-03 and UNK-09 were fired by the same firearm as TF-01. Figure 20 shows the corresponding tabulated results with image comparison examples, and the RBL Graph.

	Acquisition Name 1	Acquisition Name 2	Best Phase PMS	Best Phase LCS	Best Phase FMR
●	UNK-06	TF-02-B	0.81	0.71	18.39
●	UNK-14	TF-02-B	0.81	0.69	17.91
●	UNK-09	TF-01-B	0.78	0.65	16.30
●	UNK-03	TF-01-A	0.74	0.66	15.68
●	UNK-03	TF-01-B	0.71	0.67	15.45
●	UNK-14	TF-02-A	0.71	0.66	15.05
●	UNK-09	TF-01-A	0.74	0.63	15.03
●	UNK-06	TF-02-A	0.71	0.61	14.10
●	UNK-05	TF-02-A	0.32	0.44	1.83



UNK-09 vs. TF-01-B



UNK-03 vs. TF-01-A

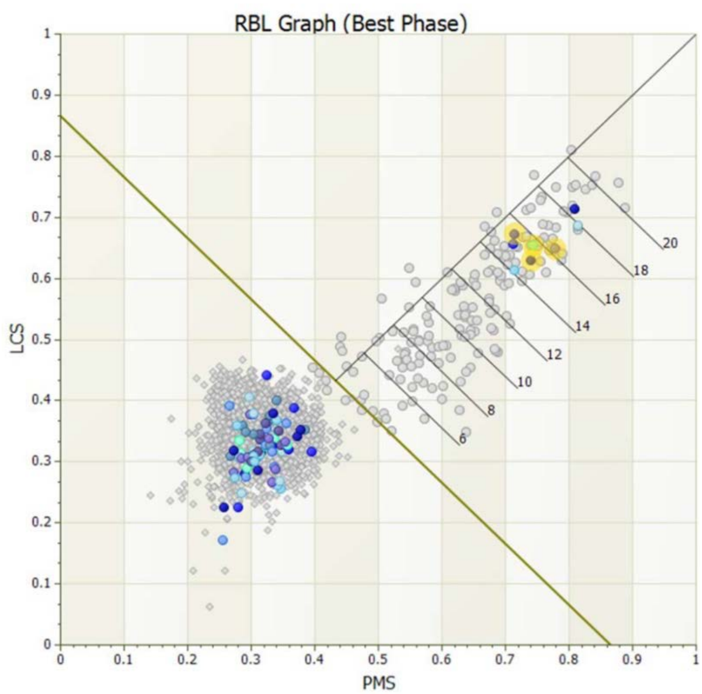


Figure 20: Q3M data for TF-01-A/B vs. UNK-03 and UNK-09 (highlighted)

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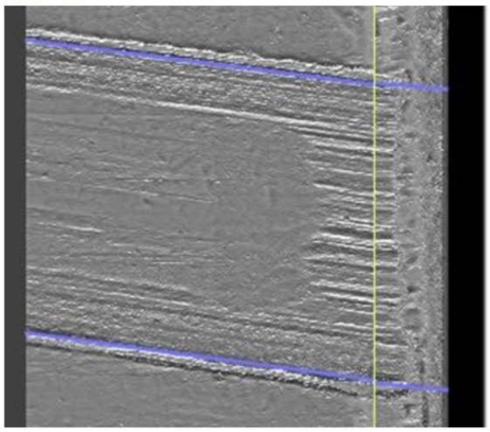
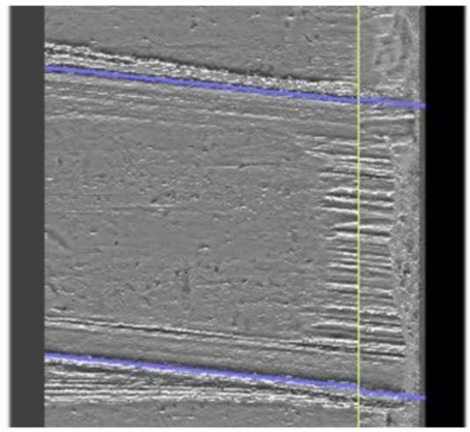
For Step 2b, the TF-02 test fires were compared with the 20 unknowns, it was determined that UNK-06 and UNK-14 were fired by the same firearm as TF-02. **Figure 21** shows the corresponding tabulated results with image comparison examples, and the RBL Graph.

	Acquisition Name 1	Acquisition Name 2	Best Phase PMS	Best Phase LCS	Best Phase FMR
●	UNK-06	TF-02-B	0.81	0.71	18.39
●	UNK-14	TF-02-B	0.81	0.69	17.91
●	UNK-09	TF-01-B	0.78	0.65	16.30
●	UNK-03	TF-01-A	0.74	0.66	15.68
●	UNK-03	TF-01-B	0.71	0.67	15.45
●	UNK-14	TF-02-A	0.71	0.66	15.05
●	UNK-09	TF-01-A	0.74	0.63	15.03
●	UNK-06	TF-02-A	0.71	0.61	14.10
●	UNK-05	TF-02-A	0.32	0.44	1.83



UNK-06 vs. TF-02-B (LEA 3)



UNK-14 vs. TF-02-B (LEA 4)

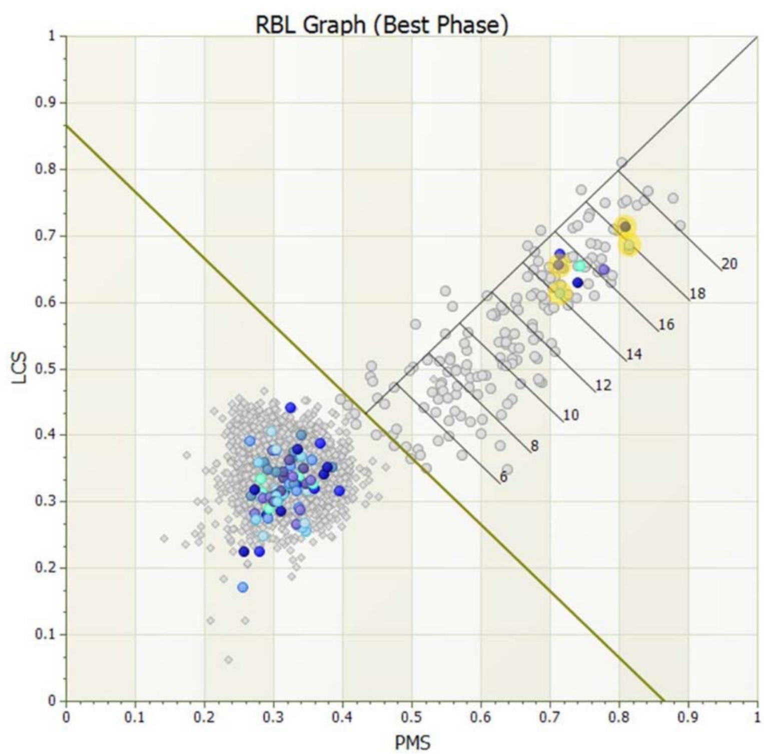


Figure 21: Q3M data for TF-02 vs. UNK-06 and UNK-14 (highlighted)

After the four unknowns were linked to the two firearms represented by the submitted test fires, quantitative analysis was used to determine which of the remaining 16 unknowns should be compared with one another (Step 3). Figure 22 shows a portion of the tabulated results and the RBL Graph for this quantitative analysis.

Acquisition Name 1	Acquisition Name 2	Best Phase PMS	Best Phase LCS	Best Phase FMR
UNK-07	UNK-15	0.63	0.54	10.71
UNK-13	UNK-17	0.58	0.49	8.66
UNK-04	UNK-17	0.51	0.50	7.23
UNK-07	UNK-19	0.52	0.45	6.15
UNK-04	UNK-13	0.47	0.48	5.97
UNK-05	UNK-20	0.39	0.50	4.69
UNK-07	UNK-11	0.49	0.38	4.33
UNK-11	UNK-15	0.49	0.39	4.32
UNK-11	UNK-19	0.44	0.42	3.84
UNK-15	UNK-19	0.47	0.36	3.24
UNK-05	UNK-13	0.40	0.39	2.30
UNK-01	UNK-17	0.42	0.34	1.85
UNK-08	UNK-16	0.39	0.38	1.79
UNK-13	UNK-20	0.33	0.44	1.78
UNK-01	UNK-13	0.39	0.37	1.68
UNK-01	UNK-15	0.38	0.38	1.64

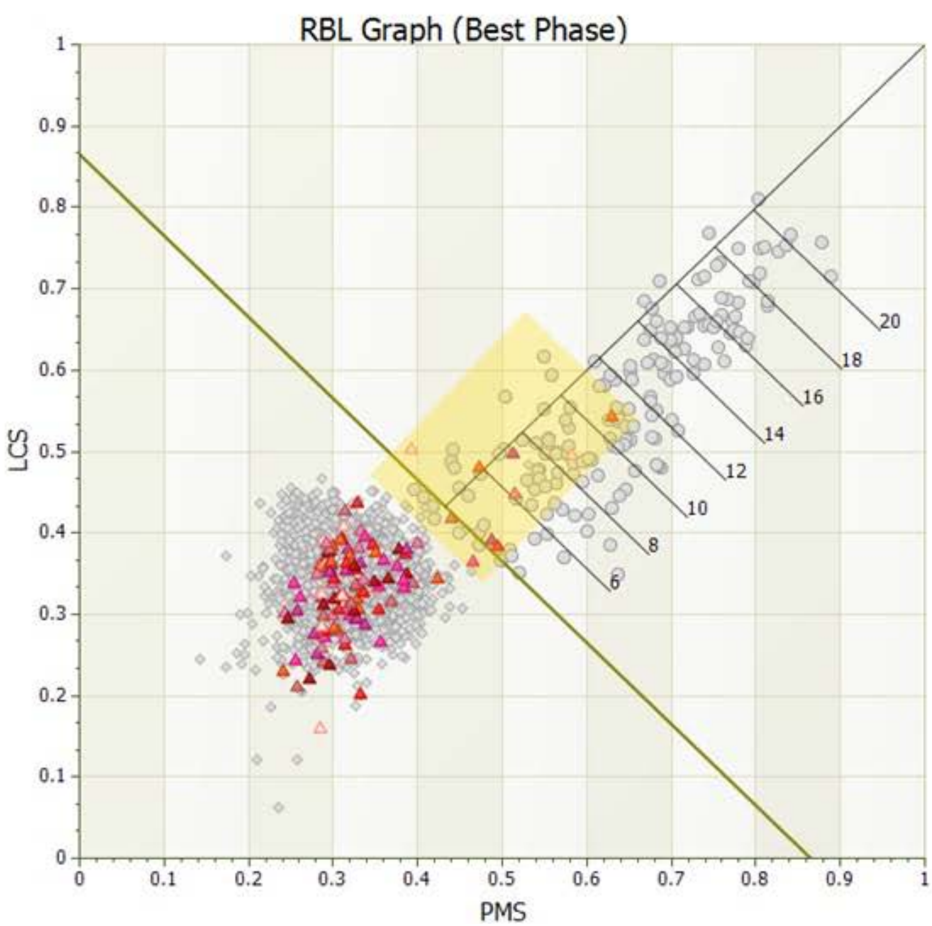


Figure 22: Tabulated results (partial) and RBL Graph for 16 remaining unknowns

Using Q3M, the following conclusions were confirmed for the unknowns that were not previously identified to the submitted test fires. Three different groups of unknowns were identified:

- UNK-05 and UNK-20 were identified as having been fired by the same firearm.
- UNK-04, UNK-13, and UNK-17 were identified as having been fired by the same firearm.
- UNK-07, UNK-11, UNK-15, and UNK-19 were identified as having been fired by the same firearm.
- The remaining seven unknowns revealed inconclusive results.

There were clear differences in the conclusions reached using Q3M compared to conventional comparison microscopy. Positive conclusions were reached for two groups of unknowns determined to be inconclusive using conventional comparison microscopy. A positive conclusion was reached for a fourth bullet in the group of four identified unknowns when that bullet was determined to be inconclusive using conventional comparison microscopy.

4. DISCUSSION

One of the more obvious takeaways from the study was the time savings when comparing the trial sets using conventional comparison microscopy versus using the Quantum 3D Microscope. The VisionX is a well-designed comparison microscope with three different lighting options and bullet holders allowing for ease of mounting and orientation of bullets in near pristine condition. Even with this ease of bullet mounting and alignment along with the good lighting conditions, the time spent performing the comparisons on the VisionX was approximately 80 hours, that is 20 times more than the time required to perform the comparisons on the Quantum 3D Microscope. While the total number of hours was different for the second firearm examiner using the Leica comparison microscope, the time-saving factor was similar using the Quantum 3D Microscope.

One consideration that must be noted is the time required to acquire the bullets. In this study, approximately 4.5 hours were needed to acquire the 24 bullets into the Quantum 3D Microscope. This should be added to the time spent by the examiners to perform the comparisons (4 hours for the first examiner; 2 hours for the second examiner). However, this is a task that can be assigned to a technician, leaving the firearm examiner free to focus on the comparisons, a task for which they are uniquely and specially trained. Furthermore, once acquired, the bullets do not need to be re-acquired every time someone new wants to view the bullets. An analogy of this would be as if the bullets were delivered to the examiner pre-mounted on the microscope with almost limitless lighting conditions available. This allows for examinations to be repeated, unlike with conventional comparison microscopy where different microscopes are used and with which lighting conditions are difficult, if not impossible, to replicate.

It was physically and mentally taxing to perform the comparisons using conventional comparison microscopy, and not only because of the number of hours involved. The number of inconclusive results amplified this exhaustion which is a genuine concern because ambiguous datasets combined with physical and mental tiredness can lead to unintentional bias being introduced into the results. For example, there were instances where some of the inconclusive results obtained with the VisionX microscope appeared to be leaning toward a common source determination when in fact, they were fired from different firearms. In other words, with the ambiguous datasets and fatigue, too much significance was being ascribed to too little correspondence. An example of this is shown in **Figure 23**.

Figure 23: Correspondence observed between bullets from different sources

Physical and mental fatigue is a very real issue with comparison microscopy. It must be clear that the 80 hours spent on the VisionX and the 60 hours spent on the Leica performing the comparisons were not continuous sessions. They were broken into smaller segments to spread the work over the course of a full month.

No such fatigue was experienced while using the Quantum 3D Microscope which provided an overall ease of comparison versus a conventional comparison microscope. It is possible to compare two bullets (in 3D) without having seen the quantitative results, but when the bullet pair is selected from the RBL graph, it is presented in the "best match" position. This is generally the phase position examiners would find using conventional comparison microscopy, and it highlights the land-engraved areas with the highest similarity. With the Quantum 3D Microscope and its quantitative analysis, this position was obtained within seconds as opposed to the many minutes required using conventional comparison microscopy.

Once displayed on the screen, visual comparison is relatively straightforward. The 3D images can be locked and manipulated as a pair, or they can be unlocked and manipulated separately. While this can be performed on most modern current conventional comparison microscopes, typically, finer adjustments are necessary.

Furthermore, once the 3D images are on the screen, lighting angle and intensity are achieved with simple movement of the mouse. When locked, it is the same for both sides and no time is spent manually adjusting the lights. Movement of the mouse is continuous until optimal lighting is achieved. Lighting optimization can be quite time consuming when using conventional comparison microscopy. Significant time and energy are saved by using the Quantum 3D Microscope. In addition, it was discovered that optimal lighting conditions for many samples would not be possible using the VisionX in spite of its superior lighting options. Figure 24 shows a comparison of UNK-03 with TF-01-A with lighting coming from an 8 o'clock location.

Figure 24: UNK-03 with TF-01-A with lighting at 8 o'clock

As mentioned previously, working with samples on the Quantum 3D Microscope improved results believed to be inconclusive leaning towards an identification, when in fact they were fired from different firearms. Additionally, several identifications were achieved using the Quantum 3D Microscope that were inconclusive when using the Leica comparison microscope. The Leica microscope is close to 30-years old and is believed to be the average age of many microscopes in forensic science laboratories. Brand name aside, older microscopes are limited and, as a result, may not always provide the examiner with the best conditions to observe important details on the surface of bullets.

A unique advantage of the Quantum 3D Microscope is the ability to provide the courts an answer to the question – "What is the probability that these two bullets were fired from different firearms?" The courts have been asking this or similar questions for decades, looking for quantified and objective answers, and these courts have become increasingly displeased with the lack of answers. The Quantum 3D Microscope can provide an answer. For example, as shown in **Figure 25**, one bullet pair had an FMR Index of 10.71. This means that the probability that two bullets fired from a different firearm would generate a higher similarity score is 1 over 1010.71 or approximately 1 in 51,000,000,000.

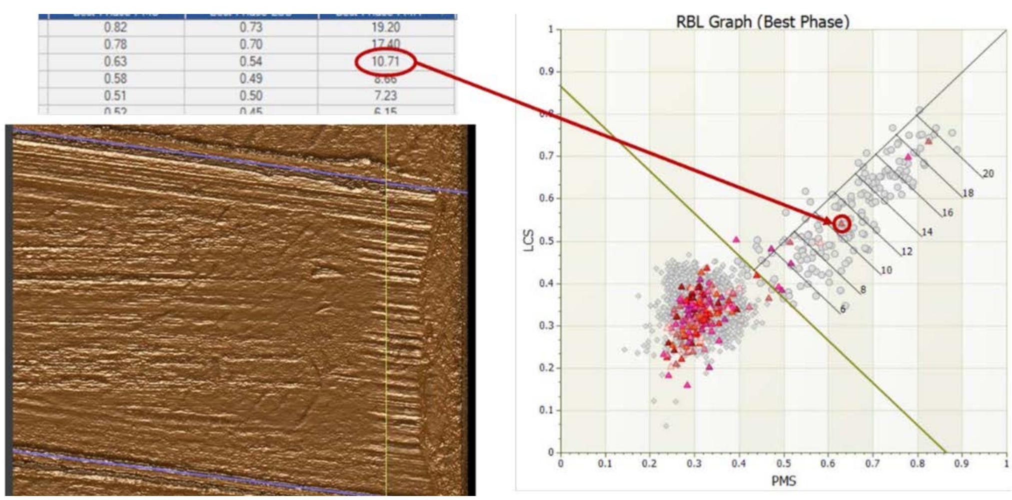


Figure 25: FMR Index 10.71

Another advantage of the FMR is the confidence it provides the examiner when the similarity score is low. When performing comparisons using a conventional comparison microscope, one of the major concerns is unintentional bias when there is a weak dataset. Examiners tend to spend a significant amount of time on such datasets, and it is not unusual for examiners to observe what they believe is significant correspondence only for it to be re-evaluated later and recognized as only incidental correspondence. However, when bullets are accessed through the RBL Graph and there is no visible correspondence (such as illustrated in **Figure 26**), an examiner can have confidence that if the bullets are shown with their best similarity, the remaining surfaces of the bullets are not likely to be of greater significance.

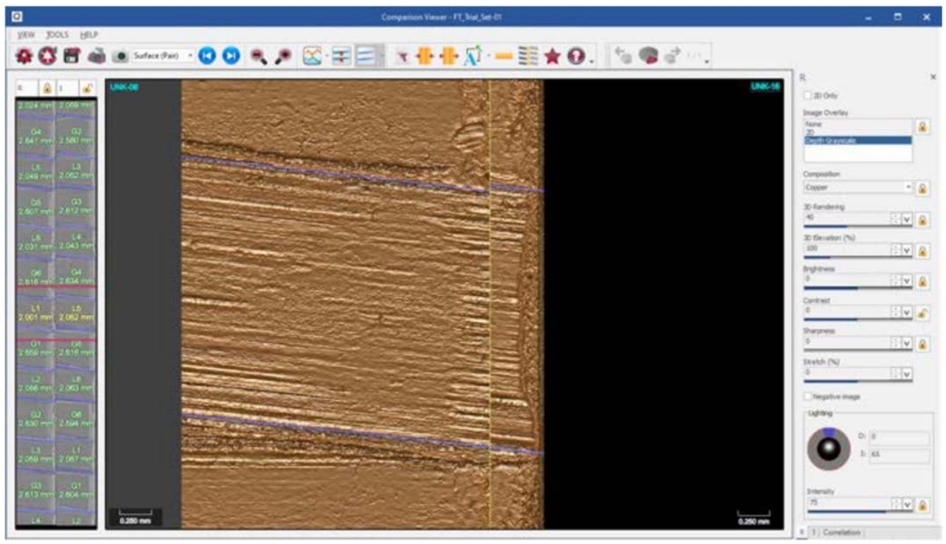


Figure 26: Different source, UNK-08 and UNK-16 – FMR index:1.79

5. CONCLUSION

The Quantum 3D Microscope has a valid place in the modern forensic science laboratory, and time efficiency is one of its major benefits. When considering time spent on bullet acquisitions and comparisons, using Q3M was 9 to 10 times quicker than using a Conventional Comparison Microscope (CCM). When factoring in the verification stage, bullets no longer need to be mounted since acquisitions have already been performed. Consequently, acquired bullets are available for verification as well as for any later comparisons for current or future cases. Moreover, each Q3M acquisition is carefully calibrated so that measurements are backed by certified reference targets. As a result, a substantial amount of time is saved through this "acquire once, re-use often" process.

Image quality is another aspect to take into consideration. The second examiner was able to conclude common source determinations using Q3M, when the same comparisons resulted in inconclusive opinions while using the CCM. The first examiner mentioned unachievable lighting conditions while using the CCM and stated that the ease in comparisons alleviated potential bias concerns. The technology behind the Quantum 3D Microscope provides much more information. This helps firearm examiners make accurate common source determinations and have more confidence in inconclusive results.

Q3M offers the courts what they have been looking for – a False Match Rate. Courts are concerned with the reliability of examiners, especially when the certainty of a common source determination cannot be articulated to their satisfaction. With Q3M, the courts can be provided with a scientifically defensible False Match Rate (FMR) that the two bullets were fired from different firearms. The RBL Graph also helps to graphically illustrate the distinction between non-matching and matching conditions. This is in line with the AFTE Theory of Identification and Range of Conclusions.

Even with the benefits of the Quantum 3D Microscope, the use of the CCM will continue for years to come. One reason is that the identification criteria upon which examiners draw their conclusions is based on a database of comparisons using CCM. Because Q3M has more information upon which identification criteria can be based, examiners will need to reassess their criteria for identification. Another reason for the coexistence of CCM and Q3M is that some objects other than bullets may be too large to fit in the 3D microscope. This is especially true when handling toolmarks from larger items and casts of marks recovered from firearm crime scenes.

The use of 3D microscopy, especially with objective results such as those provided by the Quantum 3D Microscope, has significant benefits for case work. It will also be a valuable tool for other studies, as well as for training, because it makes the sharing of data and the replication of datasets quite easy.

This study was based on the initial capabilities of this technology, and Ultra Forensic Technology is already at work on additional innovations that will expand the value of 3D microscopy for firearm and toolmark identification.

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