UNIVERSITY OF CENTRAL OKLAHOMA

GRADUATE COLLEGE

INVESTIGATING THE BALLISTICS IQ TRIAGE

A THESIS

SUBMITTED TO THE GRADUATE FACULTY

in partial fulfillment of the requirements for the

Degree of

MASTER OF FORENSIC SCIENCE

By:

HAILEY CARTER

EDMOND, OKLAHOMA

2025

INVESTIGATING THE BALLISTICS IQ TRIAGE

A THESISAPPROVED FOR THE

W. ROGER WEBB FORENSIC SCIENCE INSTITUTE

By _____

Eric Law, Ph.D. Committee Chairperson

_____

Craig Gravel, M.A. Committee Member

_____

Rachel Bolton-King, Ph.D. Committee Member

Abstract

Ballistics IQ (BIQ) is one of several instruments used to assist forensic practitioners in making comparisons about cartridge cases along with indicating the possible number of firearms used on scene. BIQ came to fruition in 2019; however, there are very few published articles discussing its triage capabilities or performance at comparing cartridge cases. With that, this study focused on evaluating the performance of the BIQ Crime Scene Analysis (CSA) Triage Report by using three hundred (300) cartridge cases, ten (10) firearms, and six (6) brands of 9mm ammunition. Each firearm was shot thirty (30) times using five (5) shots each of six (6) ammunition brands. This study started off by conducting several tests on the metadata information that users enter when imaging cartridge cases. After evaluating the metadata effects, the CSA Triage algorithm was tested. A CSA Triage report was conducted for all three hundred (300) cartridge cases used throughout this study and the BIQ Triage concluded that all cartridge cases originated from seven (7) firearms; however, the ground truth was that there were ten (10) firearms. This output caused further analysis to take place which resulted in ten (10) additional CSA Triage reports being conducted. Each CSA Triage report contained thirty (30) cartridge cases from each firearm. Interpretation of these CSA Triage reports concluded that the BIQ Triage had difficulty with three (3) firearms (Ruger LC9, Ruger P89, and Springfield XD9) which resulted in another breakdown. Furthermore, it was concluded that the BIQ Triage had difficulty with cartridge cases of Remington and Winchester ammunition. These results indicate that forensic practitioners should use caution when using BIQ to analyze their cartridge cases as the algorithm had difficulty analyzing ten (10) commonly available firearms, as well as two (2) commonly available ammunition brands, meaning the triage algorithm may provide misleading information.

Acknowledgements

I would like sincerely to thank Dr. Eric Law for his unwavering support, guidance, and invaluable contributions to this project. I would also like to extend my gratitude to Dr. Rachel Bolton-King and Craig Gravel for their thoughtful feedback and assistance throughout this process.

I would also like to show my appreciation and gratitude to my parents, Becky and Chris Carter, for their wholehearted support. In addition to my parents, I also want to thank the rest of my family for their support throughout this experience. I could not have completed my project or graduate school if it was not for them continuously pushing me to do my best.

Table of Contents

List of Figures

List of Tables

Literature Review

Introduction

According to a survey conducted by the Bureau of Justice, 86% of crimes involve firearms (Zawitz, 1995, p. 1). Due to the amount of crime that involves firearms, it is important to determine where each cartridge case originated from. When trying to understand ballistics, it is essential that one understands the significance that ballistics holds within the forensic science field. While toolmark examination was first conducted in 1835 and firearm examination in 1852, it is important to note that ballistics examination was not coined until 1925. Ballistics examination involves analyzing firearm evidence in an attempt to trace it back to a potential crime scene firearm (National Institute of Standards and Technology, 2023). There are several instruments and databases that are used to determine where the bullet or cartridge case originated. Below the reader will explore assorted topics to help represent how ballistics came to be what it is known as today. These topics include the history of visual examination; comparison of class, subclass, and individual characteristics; systems and database development; and addressing new technological developments.

The history of visual examination is important in understanding what toolmark, firearm, and ballistics examination is. Comparison of class, subclass, and individual characteristics also holds significance because these characteristics are a crucial part of examining firearms. Without understanding these, an examiner cannot make any conclusions about the firearm evidence they are examining. Systems and database development is also important to address because the Integrated Ballistics Identification System (IBIS) and the National Integrated Ballistics Information Network Program (NIBIN) are two large hardware/databases that are currently used in the comparison of bullets and cartridge cases. The last topic, new technological developments,

is significant because novel instruments and technologies are being implemented to improve the way examiners perform comparisons. One piece of technology that will be addressed in depth is Ballistics IQ (BIQ). Due to BIQ being a novel instrument, it is unknown how well it makes comparisons. Therefore, it is important to address how BIQ came to fruition, how it can be utilized, why this technology is important, and why determining the viability of this innovative technology must be explored before large-scale use in casework.

History of Visual Examination

Toolmark examination was the first to be conducted and used to solve crimes in 1835. The first toolmark comparison involving a firearm took place in England when Henry Goddard traced a flaw in a projectile to the mold that made it (Firearm Examiner Training, 2008). A toolmark is an impression mark that occurs when a tool and surface collide with each other (Forensic Analytical Crime Lab, 2021). Toolmark examination consists of comparing striations, or impressed marks that have been left on a surface from a tool to determine what tool left that specific mark (Forensic Analytical Crime Lab, 2021). Seventeen (17) years later, in 1852, the term 'firearm examination' was adopted (Firearm Examiner Training, 2008). Firearm examination consists of comparing various features on cartridge cases and determining whether they originated from one source or two different sources (Brand et al., 2020). This kind of examination was conducted when a sheriff from Oregon performed an experiment where he fired a firearm at a shirt to determine if a bullet created the hole in the victim's shirt (Firearm Examiner Training, 2008). In 1896 the effects of test firing were first observed in a Kansas State Court (Firearm Examiner Training, 2008). During the 1900s, a journal was published listing procedures used to measure the land and groove markings on bullets (Firearm Examiner Training, 2008). In 1902, a court in Massachusetts allowed an expert to testify regarding the

effects of rifling and the other various markings left on a fired bullet (Firearm Examiner Training, 2008). Later in 1907, examiners performed an evaluation of thirty-nine (39) fired cartridge cases and linked them to the rifles that were discovered on scene (Firearm Examiner Training, 2008). This is also the first time that photographs of each cartridge case were taken through a microscope for comparisons (Firearm Examiner Training, 2008). When conducting comparisons, the examiners focused on the primer and impressions on the primer which eventually led to an identification of the model of rifle used (Firearm Examiner Training, 2008). In 1912, a French Professor named V. Balthazard used photographs to conduct a side-by-side comparison of fired bullets to specific firearms. He specifically focused on individual characteristics of land and groove markings, the firing pin, breech face marks, ejector marks, and extractor marks (Firearm Examiner Training, 2008). Ten (10) years later, during the trial of Hadley v. Arizona (1992), attorney and researcher A. J. Eddy proved to the state that firearms identification evidence was valid and admissible (Firearm Examiner Training, 2008).

In 1925, ballistics examination was discovered by Calvin Goddard and Charles Waite (Firearm Examiner Training, 2008). This led Goddard to be recognized as the father of ballistics (Teitelbaum, 2021, p. 109). Also in 1925, Goddard, Waite, John Fisher, and Philip Gravelle established the Bureau of Forensic Ballistics where they provided firearm identification training to every agency in the United States (Firearm Examiner Training, 2008; Teitelbaum, 2021, p. 111). In 1926, Goddard, Fisher, and Gravelle developed the helixometer and comparison microscope (Firearm Examiner Training, 2008; Teitelbaum, 2021, p. 110). The helixometer made it possible for analysts to examine the surface of the bore as well as measure the rifling (Teitelbaum, 2021, p. 110). The comparison microscope made it possible for two items of firearms evidence to be viewed simultaneously under microscopic conditions (Teitelbaum, 2021,

p. 110-111). In 1927, Goddard performed a ballistics examination for the Sacco and Vanzetti case where he reexamined bullets and cartridge cases to determine if they had been fired from the suspects' firearms (Firearm Examiner Training, 2008). Besides Goddard determining if any of the fired bullets or cartridge cases came from the suspects' firearm, he also demonstrated this new science to show others what ballistics examinations entailed (Teitelbaum, 2021, p. 111). In 1929, rumors in Chicago, Illinois stated that police officers participated in a massacre. Goddard used ballistic examination techniques to prove to everyone that the police were not involved in the massacre (Firearm Examiner Training, 2008). He did this by evaluating all the police officers' firearms and comparing them to the cartridge cases, bullets, pellets, and shotshell cases found at the scene (Firearm Examiner Training, 2008).

In 1930, Goddard provided firearm and toolmark identification training to several laboratories in the United States (Firearm Examiner Training, 2008). Two (2) years later, J. Edgar Hoover received training from Goddard which resulted in the establishment of the Federal Bureau of Investigation (FBI) laboratory (Firearm Examiner Training, 2008). In 1934, Colonel H. W. Todhunter introduced firearms identification to the United Kingdom where he was later recognized as the founder (Firearm Examiner Training, 2008). In 1935, the 'Textbook of Firearms Investigation, Identification and Evidence' was published which involved Julian S. Hatcher designing, manufacturing, and testing ammunition and firearms (Firearm Examiner Training, 2008). This book is still used today by many firearm examiners throughout the United States to learn about the principles of firearm identification along with reinforcing the need for a standardized methodology (Firearm Examiner Training, 2008). From 1940 to 1947, numerous crime laboratories were established to include firearm and toolmark examination (Firearm Examiner Training, 2008). In 1958, John E. Davis drafted a book called 'An Introduction to

Toolmarks, Firearms and the Striagraph' in which he talked about the examination and identification of firearms and toolmark evidence along with his development of the striagraph (Firearm Examiner Training, 2008). In 1962, Dr. J. H. Mathews published two sets of books containing information about the identification of firearms, measurements of rifling, photographs of the firing pin impressions, photographs of handguns, and other illustrations (Firearm Examiner Training, 2008). In 1963, President John F. Kennedy was assassinated and both two (2) large fragments from a bullet and three (3) cartridge cases were discovered and identified by examiners which led to the arrest of the suspect (Firearm Examiner Training, 2008).

In 1968, Martin Luther King, Jr. was assassinated, and the FBI's Firearms and Toolmarks Unit discovered that the cartridge case found on scene was a match to the rifle found on scene (Firearm Examiner Training, 2008). However, they were unable to determine if that rifle fired the bullet that was also found on scene (Firearm Examiner Training, 2008). In 1969, the Association of Firearm and Toolmark Examiners (AFTE) was founded (Firearm Examiner Training, 2008). In 1970, AFTE held their first training seminar which provided individuals with information related to firearms and toolmark identification (Firearm Examiner Training, 2008). Three (3) years later in 1973 Alan Wilimovsky and Dr. Mathews created and published a third book called 'Firearms Identification' which included information regarding data on rifling characteristics, information on revolvers and pistols that most were not familiar with, and more photographs and illustrations of firearms (Firearm Examiner Training, 2008). In 1975, the FBI conducted the first gunpowder residue and primer residue training making this one of the very first training courses for firearm examiners (Firearm Examiner Training, 2008). Several years later in 1982, AFTE published a training manual explaining to examiners how to examine firearms and toolmarks (Firearm Examiner Training, 2008). In 1998, the Scientific Working Group for Firearms and

Toolmarks (SWGGUN) was founded to develop guidelines for the firearm and toolmark comparison discipline (Firearm Examiner Training, 2008). During the trial of United States v. O'Driscoll (2003), the Supreme Court ruled that expert testimony regarding ballistics was an acceptable method to be used in trials (Firearm Examiner Training, 2008). In 2007, a court in California addressed during the trial of Edgar Diaz v. United States (2007) that a secondary examiner must verify the conclusion of the first examiner, and it should be a blind verification (Firearm Examiner Training, 2008).

Comparison of Class, Subclass, and Individual Characteristics

While the history of visual examination is noteworthy, understanding class, subclass, and individual characteristics are also significant. Through these characteristics, a firearm examiner can determine whether bullet/cartridge case A was fired by the same firearm as bullet/cartridge case B. From here, the information then goes to the local policing agency where they can use this information to arrest a suspect.

According to Charles Wilson, class characteristics are markings on a fired bullet that are similar to all other fired bullets of that same ammunition type, caliber, and make (Wilson, 1936, p. 97). In other words, class characteristics are determined before a firearm is manufactured. Examples of class characteristics include:

- A barrel's rifling direction (Carriquiry, Hare, & Hofmann, 2017, p. 2335). Once fired, the bullet twists either to the left or right, depending on the model of the firearm. The characteristics inside of the barrel impart onto the bullet with either a slight left or right tilt. Characteristics like this are easily observable and can be used to eliminate firearms evidence originating from the same source.

- The number of lands and grooves that are present on a bullet (Heard, 2008, p. 165). A bullet with eight lands and grooves can be excluded from originating from a firearm whose barrel only has six lands and grooves.
- The caliber of the ammunition fired. For instance, a 9mm cartridge case is different than a .380 cartridge case based on their length (a 9mm cartridge case is taller than a .380 cartridge case).
- The headstamp of a cartridge case. A cartridge case with WIN 9mm Luger is different from an R-P 380 Auto.
- The ejector position which can be found near the edge of the headstamp, and it is caused by the slide of the firearm hitting the cartridge case as it is being ejected.
- The extractor mark which is left on the edge of the head stamp and is established by the extractor pulling onto the case and leaving a grip impression.
- A drag mark which will be located near the firing pin, and it is established by the cartridge case encountering the firing pin when being ejected.

While class characteristics seem straightforward, it is evident that the reader understands that an examiner cannot make an identification using class characteristics, only an elimination. Identification is an agreement of class and individual characteristics signaling that two (2) toolmarks are identical (Monson, Peters, & Smith, 2022, p. 88). For instance, two (2) cartridge cases were found on scene and after examination, it was revealed that both cartridge cases had the same number of markings and looked similar. Elimination is when the individual or class characteristics are different between two (2) cartridge cases (Monson, Peters, & Smith, 2022, p. 88). The inconclusive conclusion encompasses three (3) slightly different outcomes: (Monson, Peters, & Smith, 2022, p. 88)

- Inconclusive A: There are some similarities between the two cartridge cases; however, there is not enough to say they are alike.
- Inconclusive B: There is neither an agreement nor disagreement of individual characteristics due to there being an absence, inadequacy, or lack of reproducibility.
- Inconclusive C: There is both an agreement of all class characteristics and disagreement of individual characteristics; however, there are not enough dissimilarities present for an elimination.

In much simpler words, inconclusive means that further examination needs to be conducted. For example, four (4) cartridge cases were found at a scene and taken to the lab for examination and after comparing the four (4) cartridge cases, the examiner decided that there was enough information to eliminate one of the cartridge cases, but further examination needed to be conducted on the other three.

When a cartridge case is fired, the pressures on the inside of the chamber force the cartridge case into the breech face of the firearm (Monturo, 2019, p. 75). Due to this impact, an impression of the breech face is then put onto the primer of the casing (Monturo, 2019, p. 75). That impression can be one of seven patterns: arched, parallel, granular, smooth, circular, crosshatch, or undetermined. The general marking patterns left by this impact are used as class characteristics to help determine if the unknown casing came from a particular firearm (Monturo, 2019, p. 75). While an examiner can obtain class characteristics from the breech face impression, they can also be obtained from the firing pin impression. When examining class characteristics from the firing pin, an examiner analyzes its size, shape, and other unique characteristics that identify a potential firearm (Monturo, 2019, p. 79). Another part of a cartridge case that can be

examined by class characteristics is the firing pin impression and this is created when the firing pin hits the primer on the cartridge case (Monturo, 2019, p. 84). The class characteristics that examiners look at when viewing the firing pin aperture is the shape (e.g., circle, tear drop, or rectangle) because doing so will lead the examiner to identify possible makes/models of firearms (Monturo, 2019, p. 85).

Subclass characteristics are a second type of characteristics that examiners use to make conclusions about firearms evidence. Subclass characteristics are impressions that are produced during manufacture and are similar among other items that were created by the same tool in the same estimated state of wear (Monturo, 2019, p. 219). Subclass characteristics are often mistaken to be individual characteristics; however, they are a subsection of class characteristics. *See Figure 1.* Class characteristics and subclass characteristics differ in three (3) ways:

- Subclass characteristics are produced during manufacture (Nichols, 207, p. 587).
- Subclass characteristics relate to a smaller group source (Nichols, 2007, p. 587).
- Subclass characteristics can occur from changes that occur after usage (Nichols, 2007, p. 587).

Like class characteristics, subclass characteristics can be identified when examining cartridge cases by two ways: the firing pin and the breech face. Subclass characteristics can also be found on consecutively manufactured surfaces (Monturo, 2019, p. 223-224). An example of a firearm that exhibits subclass characteristics on its breech face is the Smith & Wesson Sigma (Monturo, 2019, p. 225).

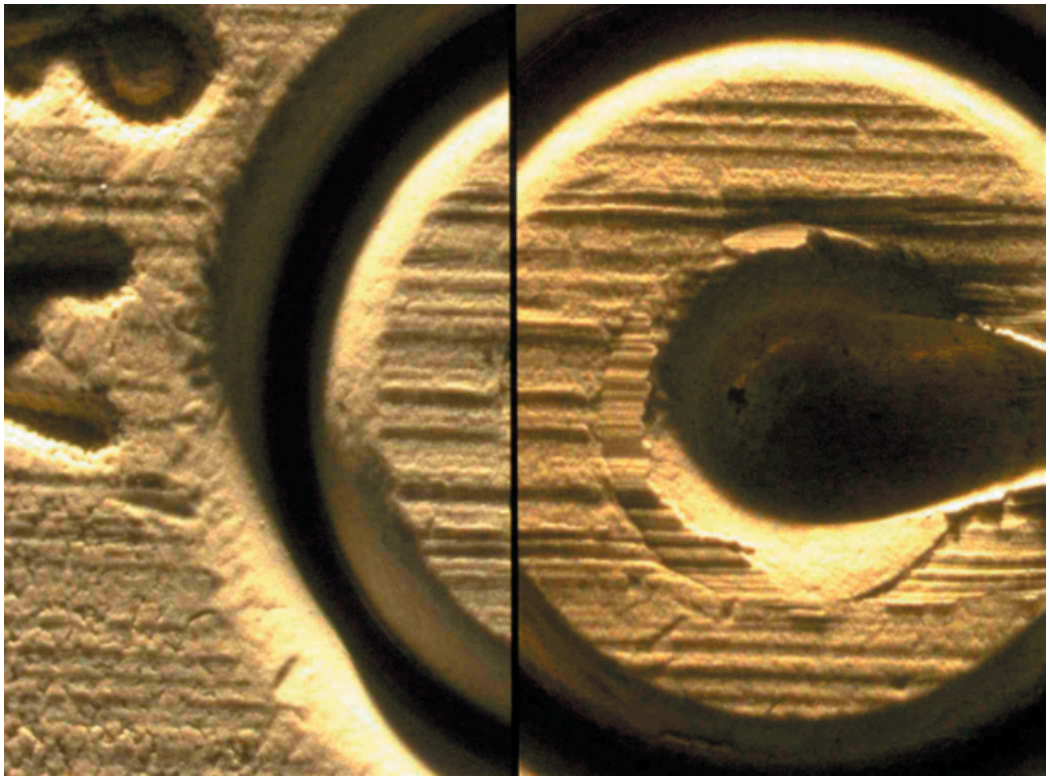


Figure 1: image of cartridge case showing subclass characteristics, Rivera 2007

The last type of characteristic is individual characteristics, or accidental characteristics (Wilson, 1936, p. 97). Individual (or accidental) characteristics are characteristics that are produced onto a tool, cartridge case, or surface during and/or after manufacturing and are considered unique (Monturo, 2019, p. 93). Individual characteristics present on a cartridge case (or any tool) after manufacture means that the characteristics were created during usage, corrosion, or damage (Monturo, 2019, p. 93). Unlike both class and subclass characteristics, the markings on a cartridge case that are identified as individual characteristics are unique, which allows examiners to make conclusions identifying the origins of the evidence (Monturo, 2019, p. 93). Individual characteristics reveal that cartridge case A was fired by the same firearm as cartridge case B. Some individual characteristics of the breech face include:

- The width and length of the striations on a breech face.
- A dent on the breech face.
- The spacing in between each of the striations on the breech face.
- Aperture shear marks which are parallel lines that are discovered around the firing pin and these marks occur from encountering the firing pin while being ejected out of the firearm. *See Figure 2*.

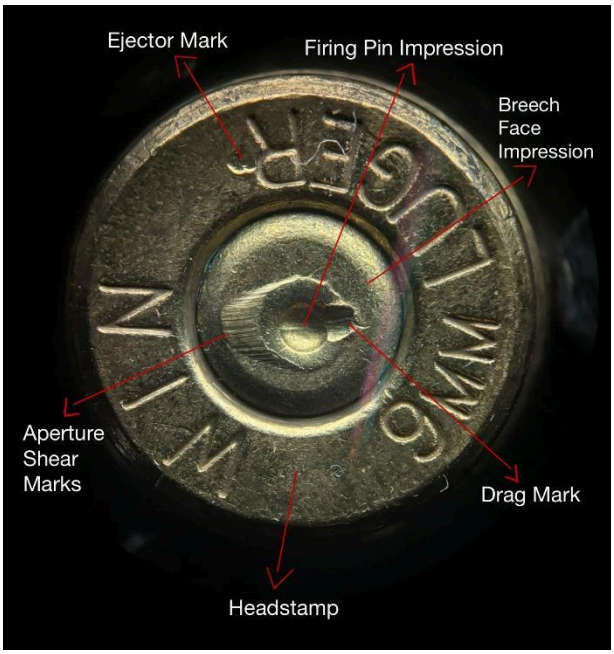


Figure 2: image of cartridge case with labeled characteristics

While class, subclass, and individual characteristics are important to understand, it is also worthy to note that there is no specified number of characteristics an examiner must obtain to make a conclusion. As an example, an examiner is comparing a known and unknown cartridge case and during this comparison, the examiner determines that ten (10) characteristics are enough to make an identification. However, a second examiner states that twenty (20) characteristics are sufficient to make an identification, and a third examiner determines that only five (5) characteristics are necessary. As one can see, the number of individual characteristics to determine sufficient agreement or disagreement is up to individual examiners.

System and Database Development

While the historical analysis of visual examination and the diverse characteristics are important for ensuring assessment accuracy, the significance of systems and databases is equally crucial. There are four (4) databases and five (5) systems that will be explained, including two databases that are often used today. The first system is the Federal Bureau of Investigation's (FBI) Firearms Reference Collection. This system was established in 1933 for training new firearm examiners about the various firearms, how they function, and the different operations of each firearm (Webb, 2013). The FBI's Firearms and Toolmark Unit also uses this system to help with their investigations involving firearm related evidence (Webb, 2013). For example, when a bank gets robbed and the suspect uses a firearm during the crime, the bank can then send the FBI a photograph of the suspect with the firearm. The FBI's Firearm and Toolmark Unit can then take this photo and compare the firearm in the image to their firearms to get a potential match of the make and model of that firearm. According to John Webb, a firearms examiner for the FBI's Firearm and Toolmark Unit, the collection has been useful in two ways: assisting examiners with their experience and assisting in criminal investigations by showing where a firearm came from (Webb, 2013). Not only does the FBI have their own Firearms Reference Collection but so do most forensic science laboratories (Hamby & Thorpe, 1997, p. 461). Like the FBI's Firearms Reference Collection, these other collections are used for training and examination purposes.

Besides the FBI creating the Firearms Reference Collection, they have also created a database that is significant for firearm and ballistics examinations. This database is called the FBI's computer database of General Rifling Characteristics, or the FBI's GRC File. This file was established in 1977 by the FBI's Firearms and Toolmarks unit and it was used as a comparison tool of class characteristics for bullets (Firearm Examiner Training, 2008). According to the

National Institute of Justice, the general rifling characteristics that come from a fired bullet are a sign of the brand and model of firearm that the bullet could have originated from (National Institute of Justice, 2023). This means that the FBI's GRC database will give results of potential firearms that a bullet could have been fired from (National Institute of Justice, 2023). For example, a 9mm bullet was found on a crime scene, the bullet's information was then entered into the FBI's GRC database, and the database gave the results that this bullet could have been fired from a Smith & Wesson, Glock, Kimber, and so forth. A second database, also established by the FBI, is called 'DRUGFIRE,' and it was developed in 1992 (Silbert, 1994, p. 63). This database is not only automated, but it is also an imaging system for firearms (Silbert, 1994, p. 63). In simpler words, DRUGFIRE holds the purpose of digitally photographing cartridge cases to link cases from laboratory to laboratory (Firearm Examiner Training, 2008). Two (2) years after the establishment of DRUGFIRE, a system called 'BULLETPROOF' was established to assist examiners in bullet identification (Firearm Examiner Training, 2008). According to Robert Thompson, BULLETPROOF is an automated comparison system for projectiles (Thompson, 1998, p. 94). In other words, BULLETPROOF focuses on comparing known and unknown bullets. Unknown bullets are the bullets that are found on a crime scene, while known bullets are the ones already in the system from previous crime scenes.

Later in 1995, a system called 'BRASSCATCHER' was established to assist with the identification of cartridge cases (Firearm Examiner Training, 2008). BRASSCATCHER and BULLETPROOF complement each other with the exception that this (BRASSCATCHER) system focuses on fully automated cartridge casing comparisons (Thompson, 1998, p. 94). In 1995, BULLETPROOF and BRASSCATCHER were combined to create a system called IBIS (Firearm Examiner Training, 2008). While it is important to know that the combination of

BULLETPROOF and BRASSCATCHER created IBIS in 1995, today BRASSTRAX and BULLETTRAX make up IBIS. IBIS allows examiners to virtually screen an unlimited number of cartridge cases for potential identifications (Thompson, 1998, p. 94). According to the Centre of Forensic Sciences, IBIS is also used as a screening tool to link cartridge cases between local, national, and international laboratories (Centre of Forensic Sciences, 2019, p. 1). There are two (2) components that make up IBIS, the first is Data Acquisition Station (DAS) and the second is Signature Analysis Station (SAS) (Thompson, 1998, p. 94). DAS is where the image of the cartridge case or bullet is captured (Thompson. 1998, p. 95). In other words, DAS collects the image of whatever cartridge case or bullet that was scanned through the microscope. SAS is based on characteristics of a captured image (Thompson, 1998, p. 95). In other words, SAS takes the data from DAS and performs a search to find potential identifications between the unknown and known. As one can figure, for SAS to occur, DAS must happen first.

IBIS works in a unique and complicated way. Simply put, a cartridge case or bullet is first examined through a microscope and photographs are captured. After these photographs are captured, they are then sent to DAS where data is then obtained from the photographs. After all the data is obtained, it is then sent to SAS for comparison. SAS then takes the information from DAS and searches IBIS for potential matches. In a more complex manner, a visual comparison microscope takes photographs of a cartridge case or bullet and then the photographs are sent to DAS. DAS then captures data from the photograph and then sends that information to SAS. Once SAS gets the information, the images are converted and then sent to a server which provides an arithmetic score (Demuth & Grom, 2012, p. 361). The numerical score is used to represent what image shows the highest similarity to the cartridge case or bullet in question. With that, the higher the numerical score, the more similarities are present between the two

images indicating a potential identification (Demuth & Grom, 2012, p. 361). From here, the photographs are uploaded and compared to the Canadian Integrated Ballistics Identification network, or CIBIN (Centre of Forensic Sciences, 2019, p. 1). After this, the examiner takes the information present from DAS, SAS, CIBIN, and the numerical scores from IBIS, and begins the analysis process of comparing the unknown and known images. As an example, cartridge A has a ranked numerical score of one (1); therefore, it is the first that is taken into comparison. If no identification can be made between cartridge A and the unknown cartridge, then the examiner can move to cartridge B which is ranked number two (2), and so forth. As one can conclude, an examiner cannot identify a cartridge case or bullet strictly based on what IBIS or CIBIN states, as it will not hold up in trial. Instead, an examiner must make the identification or elimination between the known and unknown.

A year later in 1996, the National Institute of Standards (NIST) was directed to assist DRUGFIRE and IBIS in identification (Firearm Examiner Training, 2008). The two being used for identification purposes led them to be combined to make the NIBIN in 1997 (Firearm Examiner Training, 2008). As stated above, IBIS collects images and data regarding bullets and cartridge/shotshell cases that are examined and used for comparison purposes. While the images are going through IBIS, they can also be compared to NIBIN (Centre of Forensic Science, 2019, p. 1). NIBIN is a national network in the United States that blends information gathered from IBIS and is managed by the Bureau of Alcohol, Tobacco, Firearms and Explosives (ATF) (Centre of Forensic Science, 2019, p. 2). NIBIN aids local, state, tribal, and federal law enforcement agencies with their ballistic imaging network system (Bureau of Alcohol, Tobacco, Firearms and Explosives). Both IBIS and NIBIN are similar in many ways such that both require an examiner to verify the results.

Another system is called the Royal Canadian Mounted Police Firearms (RCMP) Reference Table (RCMP Firearms Reference Table). RCMP is a system used to assist firearm examiners, and its reference table was established in 2017. The RCMP Firearms Reference Table was created by firearm experts from RCMP who conducted various assessments of firearms to assist law enforcement and custom officers along with other officials (Royal Canadian Mounted Police, 2023). The last system is called CartWinPro and while there is no known year that this system was established, it is yet another important system for firearm examiners. According to CartWinPro's webpage, the purpose of this system is to provide a quick and professional identification of cartridge cases and calibers by viewing the measurements of caliber, headstamp, color code, manufacturer, and cartridge records (CartWinPro, 2023). While government officials (police, forensic science experts, military specialists, and firearm examiners) use this system, museums can also use this system (CartWinPro, 2023). Even though there are multiple systems and databases that exist to assist firearm and ballistics examiners, the most commonly and widely used databases are IBIS and NIBIN.

New Technological Developments

As time progresses, many instruments, systems, and databases have been developed to assist examiners with identifications of cartridge cases and bullets. Since then, three (3) additional advancements in firearms/ballistics technology have been made: Virtual Comparison Microscopy (VCM), Cadre Forensics TopMatch-GS 3D (TopMatch), and BIQ.

VCM was coined in 2006 by Paola Fratini, Luciano Garofano, Roberto Groppetti, Michele Pierni, and Nicola Senin (Lilien, 2020, p. 2). VCM is a two-dimensional (2D) and three-dimensional (3D) imaging software that focuses on fired cartridge cases and bullets

(DiEmma, Jones, & Shute, 2022, p. 1). Even though VCM is a type of software rather than an instrument, without it, 3D imaging machines would not exist. VCM is a virtual side-by-side comparison that is done on a computer rather than using a comparison microscope (Monturo, 2019, p. 299). There are several advantages to using this software when examining cartridge cases or bullets:

- Through VCM, one has instant access to the data without needing to request or physically transfer it (Monturo, 2019, p. 299). Like all recent technology, VCM has a digital storage space which is where the historical data file is present.
- VCM is accessible, meaning that all training examples can be shared worldwide, which will give trainees at any location the chance to view cases (Monturo, 2019, p. 299).
- VCM can improve lab efficiency regarding blind verifications due to the verifications being done remotely by examiners at other locations (Monturo, 2019, p. 299).
- During examinations, the examiner can enhance and reorient the images on a computer screen to assist them in locating characteristics (DiEmma, Jones, & Shute, 2022, p. 2).

Top-Match is the first instrument added to the list, and it was founded in 2015 by Marcus Brubaker, Pierre Duez, Ryan Lilien, and Todd Weller (Brubaker et al., 2015, p. 198). TopMatch measures the 3D surface topography of cartridge cases. In addition, TopMatch can also compare the breech face and aperture shear marks by using its algorithm (Brubaker et al., 2015, p. 199). There are two stages that make up TopMatch and they are scan acquisition and scan comparison, or VCM. When comparing breech face impressions, there are built-in algorithms that assist in

identifications which recognize a set of features that are similar between the two cartridge cases (Brubaker et al., 2015, p. 202). Examiners can then make a conclusion on whether the cartridge cases originated from the same source.

The latest instrument to be added to the way that examiners make comparisons is called BIQ. BIQ was established in 2019 by a company called Evidence IQ. Like the previous instruments/software mentioned, this instrument holds the purpose of examining fired ammunition components. However, unlike the other instruments, BIQ only focuses on cartridge cases and is portable. Rocky Edwards and Stephanie Luehr state that BIQ was created solely for the purpose of a group of people wanting to help battle against gun crime (Edwards & Luehr, 2021, p. 1). BIQ works in a unique way. According to Evidence IQ, right after a shooting incident occurs, one can scan cartridge cases using BIQ and upload those photographs to the BIQ investigative portal. Within minutes, a Crime Scene Analysis (CSA) Triage Report is created which groups the cartridge cases into three distinct categories: High Confidence, Low Confidence, and Undetermined. The CSA Triage Report also selects the best cartridge case for entry into NIBIN (Evidence IQ). As an example, seven (7) casings were discovered at a scene, the examiner or crime scene investigator would put the casings into this instrument and let it take photographs of them. After the photographs have been taken, the examiner would then run the images into the BIQ investigative portal. Once this has been completed, a CSA Triage report tells examiners that out of all seven (7) casings found on scene, three came from one firearm while the other four came from a second firearm. The examiners would then take this information and begin their analysis comparing casings to IBIS and NIBIN. Once the examiners make their identifications, they would present the information to the investigating agency where they can arrest the suspect.

The BIQ instrument includes six (6) capabilities: (1) Mobility, (2) Virtual Correlation Center (VCC) Access, (3) Timely Results, (4) Cost Effective, (5) Triage, and (6) Documentation (Edwards & Luehr, 2021, p. 1).

The first capability of BIQ is its mobility. With this capability, BIQ can be easily transported from scene to scene as it has a camera that acts as a microscope and takes approximately thirty (30) seconds to scan a cartridge case (Edwards & Lueher, 2021, p. 1). Not only does this instrument provide portability, but if an internet connection is not available on scene, BIQ can still scan cartridge cases that can be later uploaded to the BIQ server once an internet connection is available (Edwards & Luehr, 2021, p. 1).

VCC is the second capability, and it allows agencies to view the CSA Triage report by remote (Edwards & Luehr, 2021, p. 2). From here, various firearms examiners can review the CSA Triage report for potential linkages within the BIQ database (Edwards & Luehr, 2021, p. 2). VCC being remote also allows retired firearm examiners to review the cartridge cases within a CSA Triage report and contact the agency that originally scanned the cartridge cases to let them know of any errors in entries or orientation issues (Grassel & Jones, 2022, p. 44).

Timely results are the third capability of BIQ (Edwards & Luehr, 2021, p. 2). This capability is guaranteed to have results back to an agency within twenty-four (24) hours of submission, but for most cases it only takes about two (2) hours (Grassel & Jones, 2022, p. 42). This is important to know because the main goal of firearm examiners is to identify where the cartridge case originated from; therefore, having a quick turnaround time is crucial.

The fourth capability is that BIQ is cost effective. According to Edwards & Luehr, this instrument was made so that smaller and mid-sized agencies who have little funding can obtain

this machine (Edwards & Luehr, 2021, p. 3). This is crucial because most small and mid-sized agencies do not obtain a lot of funding and therefore cannot perform their own examinations unless they give the evidence to a larger agency. The downside of this is that the smaller or mid-sized agencies might have to wait for the larger agency to have time to examine the evidence. By making the BIQ instrument cost effective, this allows those smaller and mid-size agencies to have access to this instrument so that they do not have to wait around for the larger department to examine their evidence.

The fifth capability of BIQ is its triage. The triage answers questions that an investigator needs to know the answer to as soon as possible (Edwards & Luehr, 2021, p. 3). For instance, the triage can answer the following questions:

- How many shots were fired?
- How many firearms were involved?
- How many shooters or suspects should we look for?
- Were these cartridge cases found at another scene?

Documentation is the sixth capability and while most firearms units and laboratories do not have a detailed documented triage system, BIQ provides documentation of cartridge casing triage, NIBIN selection, and potential link information (Edwards & Luehr, 2021, p. 3). Besides these two (detailed documented triage systems and photographs) all the information that BIQ provides examiners with can be used in criminal proceedings (Edwards & Luehr, 2021, p. 3).

While a lot has been discussed regarding BIQ, it is important to note that since BIQ is a newer instrument, there are not a lot of peer-reviewed publications regarding it. However, Evidence IQ lists several advantages to using this instrument:

- BIQ is portable and can be transported from scene to scene and has the ability to connect to your computer via USB (Evidence IQ).
- The examiner can get instant results which, as mentioned above, can help agencies solve cases quicker by telling examiners and detectives a specific number of firearms to search for (Evidence IQ).
- BIQ can be used with any internet-connected computer and the images can be downloaded at any given time (Evidence IQ).
- Both money and time are saved since this instrument can solve crimes quicker than other instruments (Evidence IQ).

Even though BIQ has several advantages, it is important to know that only forty (40) agencies have this instrument (Aguirre, 2022). While forty (40) agencies have this instrument, as of the current time, the number of agencies that have used it to solve their crimes is unknown. Due to this, there is a research gap in the viability of the automated triage component of this instrument and if this instrument would be useful for practitioners to use in casework.

Summary

Overall, there are several publications online regarding the diverse types of examinations (toolmark, firearm, and ballistics), the various systems and databases (IBIS, NIBIN, etc.), and two out of the three new instruments/software's (Top Match and VCM); however, there is not much for BIQ. As a refresher, BIQ is a portable instrument that examines cartridge cases in a quick manner and was coined in 2019. The topics covered in this literature review were (1) the history of visual examination; (2) comparison of class, subclass, and individual characteristics; (3) systems and database development; and (4) new technological developments. When

conducting research, the writer discovered four (4) publications for the history of visual examination, six (6) publications for the diverse types of characteristics, eleven (11) publications for the various systems and databases, and seven (7) publications for new technological developments. Even though seven (7) publications were found for the new technological developments section, only three (3) were for BIQ. Two of the publications regarding BIQ came from the company itself, while the last publication came from a news webpage. Due to the limited peer-reviewed research regarding BIQ, it leads to the question of how accurate is the BIQ triage and would it be beneficial for practitioners to use during casework?

Methodology

Ballistics IQ (BIQ) is an instrument that was developed by a company called Evidence IQ in 2019. Even though BIQ was created in 2019, there is limited published information describing the performance of its algorithms. The goal was to determine how effective the BIQ triage algorithm is when making comparisons. The viability of the BIQ triage needs to be addressed for one main reason: if practitioners are going to effectively use this within their casework, they need to know that this instrument can assist them. For instance, the BIQ triage can assist crime scene investigators with an on-site rapid triage that determines the number of possible firearms used at a crime scene. The BIQ triage can also assist law enforcement by providing quick investigative leads and accelerating the process of solving cases. Throughout this study, the goal was to use quantitative assessment; however, qualitative assessment was also used.

Equipment Utilized

BIQ is an instrument that holds the ability to photograph cartridge cases and utilizes an advanced algorithm that analyzes the images of the cartridge case features *(see Figure 3)*. These features are then used to find potential links to other cartridge cases in an attempt to determine

the number of firearms used at the scene of a crime. The images are taken within approximately a thirty second period at four different light positions and each lighting shows various characteristics of the cartridge case. Prior to taking photographs of the cartridge cases, BIQ has five applications that must be confirmed: Caliber, Breech Face, Orientation, Firing Pin, and Aperture Shear Marks (*see Figure 4)*. It is important to note that BIQ works for both centerfire and rimfire cartridge cases; however, this study focused on centerfire. Centerfire cartridge cases were the focus of this study because they are commonly discovered at crime scenes due to their high caliber and likelihood of causing damage. Another important aspect of BIQ is that the user can select manual focus or auto focus, but for this study auto focus was used to eliminate manual focus variation. After the scanning process was completed, the cartridge cases were sent to BIQ's cloud where the photos were stored. After all cartridge cases had been imported into the cloud, they could then be triaged using the "CSA Triage Report" function. After the report gives the user its comparisons, the user can then view each individual cartridge case and make their conclusions using side-by-side comparisons (*see Figure 5)*.

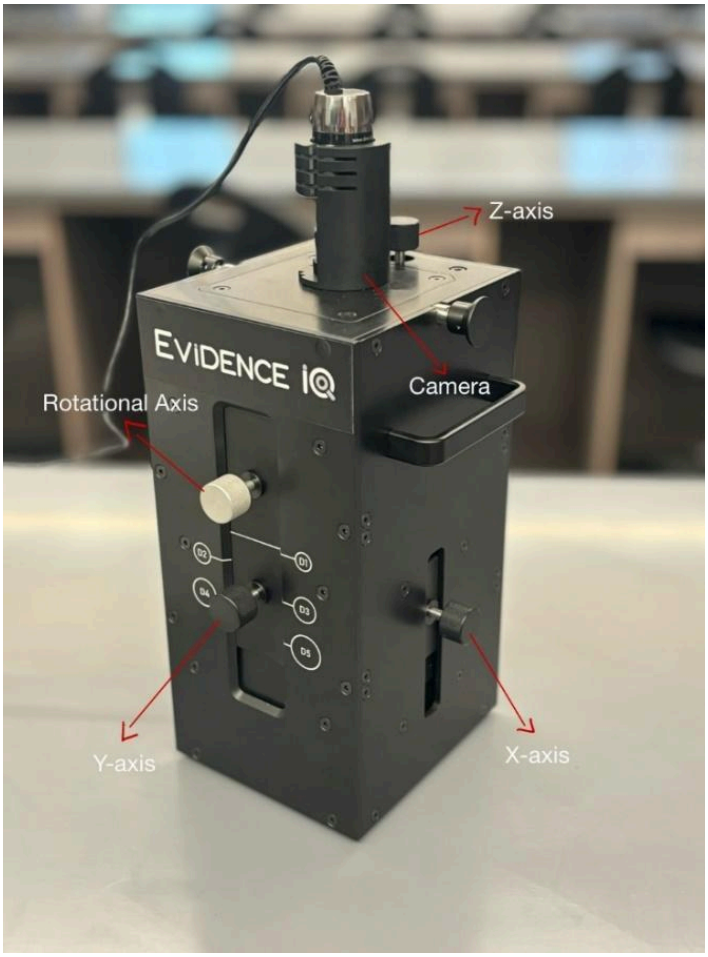


Figure 3: Image of Ballistics IQ (BIQ) instrument with camera, x-axis, y-axis, and z-axis labeled.

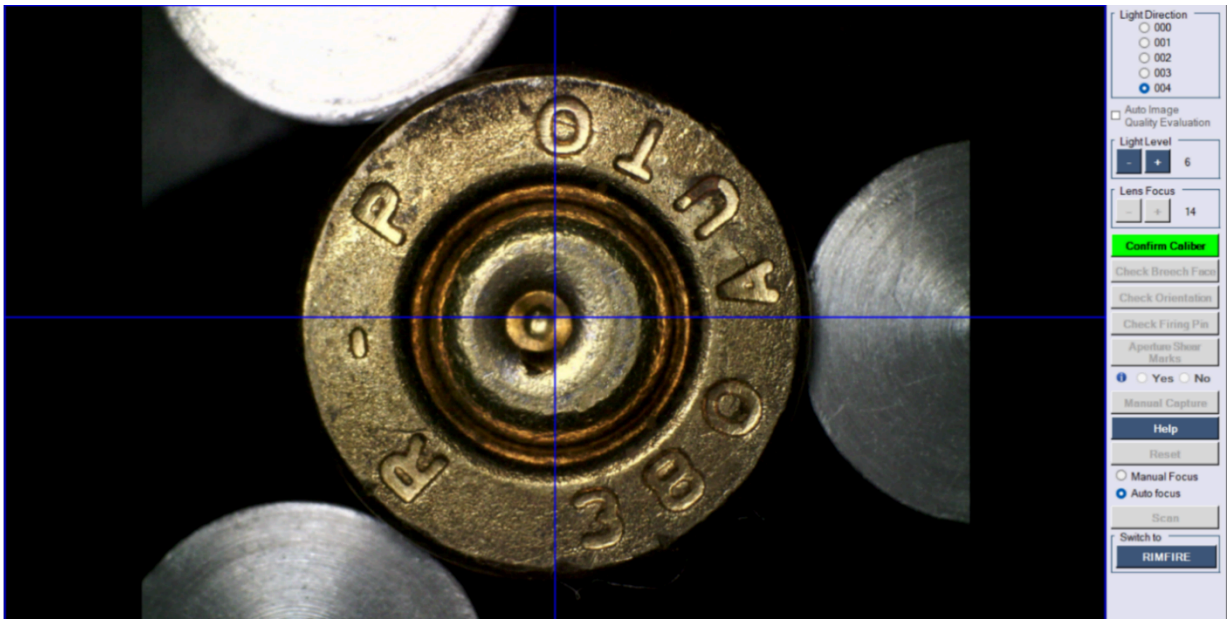


Figure 4: image of process prior to scanning cartridge cases. Involves confirming Caliber, Breech Face, Orientation, Firing Pin, & Aperture Shear Marks

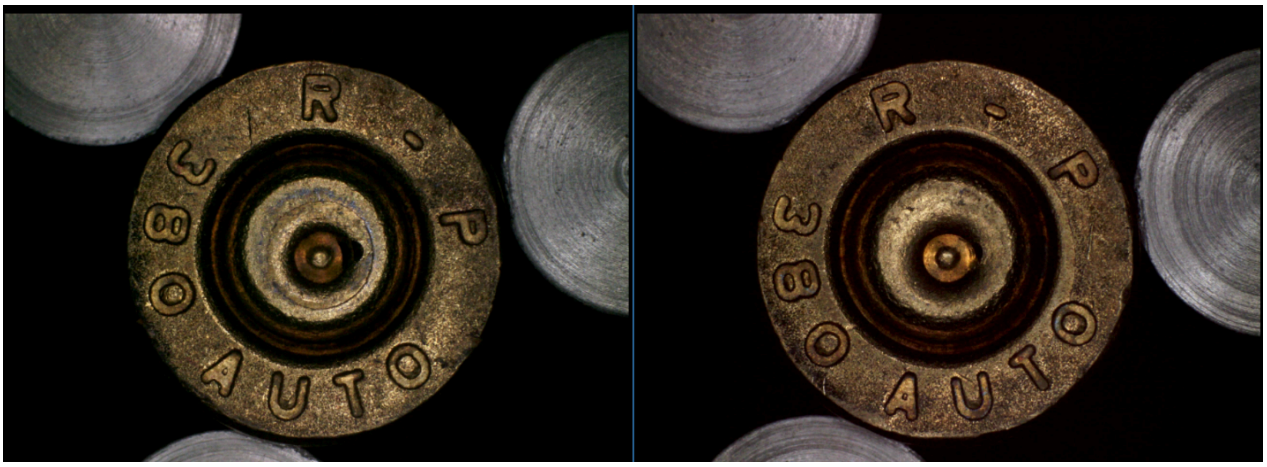


Figure 5: image of side-by-side comparison of two cartridge cases.

Experimental Design

This study involved cartridge cases from ten casework firearms. The firearms involved in this study were a Beretta 92FS, Glock 19, Hi-Point C9, Ruger LC9, Ruger P89, Smith & Wesson SD9VE, Smith & Wesson M&P9, SCCY CPX, Springfield XD9, and Taurus PT92. These

selected firearms were test-fired because they are commonly available and chambered in 9mm Luger, which is a caliber commonly found on crime scenes. Thirty shots were fired from each firearm for a total of three hundred (300) collected cartridge cases. Each cartridge case has a four (4) letter identifier engraved into its side to keep track of ground truth. There are six distinct brands of ammunition that were used for this study: Winchester, Remington, Maxx Tech, Wolf, CCI, and Blazer. Not only are these ammunition brands commonly available, but different ammunition brands have been found to reproduce marks in different ways (Davis, 2010). In addition to this, some ammunition brands are made of different metals. *See Table 1 and Figure 6.* Each ammunition brand was shot five times from each firearm. *See Table 2.* This dataset was also used in a previous study to evaluate a Cadre Forensics TopMatch GS 3D System (Alsdurf, Law, & Luehr, 2024).

Table 1: the metal within the various ammunition brands utilized in this study.

Ammunition Brand	Primer Material	Cartridge Case Material
Winchester	Brass	Brass
Remington	Brass	Brass
Maxx Tech	Brass	Steel
Wolf	Brass	Steel
CCI	Nickel	Aluminum
Blazer	Nickel	Brass

Blazer Ammunition

Maxx Tech Ammunition

Wolf Ammunition

Remington Ammunition

Winchester Ammunition

CCI Ammunition

Figure 6: all six ammunition brands used in this study.

Table 2: the ten firearm models and six ammunition brands used in this study. There were five shots per firearm/ammunition combination.

		Ammunition brand					
Firearms (manufacturer & model)		Winchester	Remington	Maxx Tech	Wolf	CCI	Blazer
Beretta	92FS	5	5	5	5	5	5
Glock	19	5	5	5	5	5	5
Hi-Point	C9	5	5	5	5	5	5
Ruger	LC9	5	5	5	5	5	5
Ruger	P89	5	5	5	5	5	5
S&W	SD9VE	5	5	5	5	5	5
S&W	M&P9	5	5	5	5	5	5
SCCY	CPX	5	5	5	5	5	5
Springfield	XD9	5	5	5	5	5	5
Taurus	PT92	5	5	5	5	5	5

The study started off by placing one (1) out of the three hundred (300) cartridge cases mentioned above into BIQ and using the various axes to ensure that the cartridge case was in its proper position *(refer to Figure 3)*. Once this was completed, a lighting direction was selected that best showed the class and individual characteristics. This was done so that confirmation of the caliber, breech face pattern, orientation, firing pin, and aperture shear marks could easily be accomplished *(refer to Figure 4)*. After this, BIQ began imaging the cartridge case and during this process, various information such as location of the incident and case number were entered into the system. Approximately thirty seconds later the cartridge case was done scanning and was imported to BIQ which automatically stored them to the Evidence IQ cloud server. This entire process was repeated until all three hundred (300) cartridge cases were imported. After

importation was completed, various factors were tested to evaluate their effects on the triage algorithm for all three hundred (300) cartridge cases: checking of the edges, re-scanning and re-rotating the cartridge cases, changing the category from recovered to test-fired, and comparisons of the breech face patterns.

Edge Check:

Edge checks were conducted on all three hundred (300) cartridge cases as a quality control to ensure that all cartridge case edges were properly entered and not too small or large. This was completed by selecting a cartridge case under "HC Thesis" and pressing "edit cartridge case edge" twice and then moving the circle surrounding the cartridge case outward to make larger and inward to make smaller. After the cartridge case edge had been changed, if needed, "update cartridge case edge" was selected and the new cartridge case edge was saved. *See Figure 7.*

Figure 7: image of edge. Brightness intensity is automatically selected from BIQ and is increased to better visualize edge.

Rotation Effects:

Twenty-one (21) cartridge cases were re-scanned for the rotation effects part of this study. Sixteen (16) cartridge cases originated from the HiPoint C9 and the other five (5) cartridge cases originated from the Smith & Wesson M&P9. There were four (4) ammunition brands that were re-scanned for the HiPoint C9. Those ammunition brands were Wolf, Maxx Tech, Remington, and Winchester. There was only one (1) ammunition brand re-scanned for the Smith & Wesson M&P9 and that was CCI. All cartridge cases that were re-scanned were labeled as __ - R#. As an example, OZBZ is one of the cartridge cases used within this study and once it was re-scanned, the new case number for it became OZBZ – R12. The "R" illustrated that it had been re-scanned and the "12" illustrated that it was the twelfth (12) cartridge case to be re-scanned.

All re-scanned cartridges were re-oriented as well. This was conducted to address two (2) questions:

- Question 1: If the parallel marks on the breech face are changed from left-right to up-down, can the BIQ triage recognize that the cartridge cases originated from the same firearm even if the orientation is incorrect?

To answer this question, the HiPoint C9 was used along with the re-scanned cartridge cases for the following ammunition brands: Wolf, Maxx Tech, Remington, & Winchester. Each ammunition brand had five (5) cartridge cases that were re-scanned and for each ammunition brand, all parallel marks on the breech face were changed from left-right to up-down. *See Figure 8.* A CSA Triage report was then conducted for each ammunition brand then it was viewed and saved.

Figure 8: image of parallel breech face pattern changed from left-right to up-down.

- Question 2: If the drag mark and ejector mark are flipped 180º, can the BIQ triage recognize that the cartridge cases originated from the same firearm even if the drag mark and ejector mark are not in correct orientation?

To answer this question, the Smith & Wesson M&P9 was used along with the ten (10) cartridge cases from the CCI ammunition. Five (5) of those cartridge cases were the original cartridge cases in correct orientation; however, the other five (5) were the re-scanned cartridge cases. For the five (5) cartridge cases that were re-scanned, the orientation of the drag mark had been changed from three o'clock (3:00) to nine o'clock (9:00) and the ejector mark had been changed from eleven o'clock (11:00) to four o'clock (4:00). *See Figure 9.* A CSA Triage report was then conducted, viewed, and saved for all ten (10) cartridge cases.

Figure 9: image of the drag mark changed from 3 o'clock to 9 o'clock & the ejector mark changed from 11 o'clock to 4 o'clock.

Recovered vs Test-Fired:

Two steps were carried out to test how the BIQ triage compares cartridge cases when they are classified as recovered or test fired. The first part of testing this factor was conducted to determine if having a cartridge case labeled as "recovered" or "test-fired" influenced the way the BIQ triage performed its analysis. Two (2) firearms were used: HiPoint C9 and Smith & Wesson M&P9. The amount of ammunition used for this section consisted of the cartridge cases that had been re-scanned from each firearm. The point of this section was to make the BIQ triage compare a selected number of cartridge cases from a specific firearm to one another to see if the category changed its results.

When using HiPoint C9, four (4) ammunition brands were tested: Wolf, Maxx Tech, Remington, and Winchester. These ammunition brands were utilized because they were the ones that were re-scanned. Regardless of the amount of cartridge cases within each ammunition type, a total of three (3) CSA Triage reports were conducted for each ammunition brand. The first (1st)

triage report was conducted for the cartridge cases categorized as "recovered", a second (2nd) triage report was conducted for the cartridge cases categorized as "test-fired", and the third (3rd) triage report was conducted for all cartridge cases together. The first (1st) two (2) CSA Triage reports were done to see how the BIQ triage analyzed the cartridge cases separately. The third CSA Triage report was conducted to test the BIQ triage itself and used as a comparison tool to see if all the triage reports matched.

The first (1st) ammunition brand tested for the HiPoint C9 was Wolf. A total of six (6) cartridge cases were tested, three (3) of those cartridge cases were re-scanned and therefore categorized as "test-fired" and the other three (3) cartridge cases were categorized as "recovered". Maxx Tech was the second (2nd) ammunition brand tested with a total of ten (10) cartridge cases. Five (5) of those cartridge cases were re-scanned and categorized as "test-fired" while the other five (5) were categorized as "recovered". Remington was the third (3rd) ammunition brand test. There were a total of six (6) cartridge cases that were tested. The three (3) cartridge cases that were re-scanned for this ammunition brand were categorized as "test-fired" and the other three (3) cartridge cases were categorized as "recovered". Lastly, ten (10) cartridge cases were tested from Winchester ammunition. Five (5) of those cartridge cases had been re-scanned and then categorized as "test-fired", while the other five (5) cartridge cases were categorized as "recovered". A CSA Triage report was conducted for each ammunition brand and its number of cartridge cases. That same CSA Triage report was then viewed and saved.

When using the Smith & Wesson M&P9, CCI was the only ammunition brand used. With the CCI ammunition, a total of ten (10) cartridge cases were tested. Like the cartridge cases above with the HiPoint C9, a total of three (3) CSA Triage reports were conducted, viewed, and

saved for the CCI ammunition. A CSA Triage report was first (1st) conducted for the five (5) cartridge cases that had been re-scanned and categorized as "test-fired". A second (2nd) CSA Triage report was conducted for the five (5) cartridge cases categorized as "recovered". A third (3rd) CSA Triage report was then conducted for all the (10) cartridge cases.

The second part of testing this factor was conducted to determine if the firearm information for test-fired influenced the way the BIQ triage performed its analysis. This was a question that needed to be addressed because when scanning and importing a cartridge case into the BIQ cloud, you are given the option to enter various information regarding a cartridge case, such as the firearm model and serial number. Since this is an option for BIQ, it was important to determine if the information entered had an impact on how the BIQ triage performed its analysis. There were two (2) firearms, and two (2) cartridge cases utilized for this part. The first firearm used was a Glock 19 and the cartridge case used was labeled as SONI. The second firearm used was a Smith and Wesson SD9VE and the cartridge case used was labeled as ZEBO. Both cartridge cases were Winchester ammunition. To test this factor, it was apparent that the same ammunition type be used to ensure accuracy since different ammunition brands have different individual characteristics. When testing this factor, both cartridge cases were first categorized as "recovered" and then a CSA Triage report was conducted, viewed, and saved. Both cartridge cases were then categorized as "test-fired" and information for the Smith & Wesson SD9VE was entered for both cartridge cases, even though they originated from two (2) different firearms. A CSA Triage report was then conducted, viewed, and saved.

Breech Face Patterns:

To test the BIQ triage using breech face patterns, two (2) cartridge cases were chosen from the Ruger LC9 model and Maxx Tech ammunition: ADCH and BMWT. *See Figure 10*.

This was conducted to determine if the BIQ Triage automatically compared one breech face pattern to another or if it combined similar breech face patterns. Determining if the BIQ Triage can recognize the different breech face patterns is important because each pattern is considered to be a class characteristic and helps identify which firearm it derived from. If the BIQ Triage cannot notice the differences between the breech face patterns, then there is a possibility it can group incorrect cartridge cases. After selecting the two (2) cartridge cases, a CSA Triage report was conducted for both cartridge cases with their original breech face pattern. Once the CSA Triage report had been viewed and saved, the breech face pattern and orientation were changed for one of the cartridge cases to parallel. A second CSA Triage report was conducted, viewed,

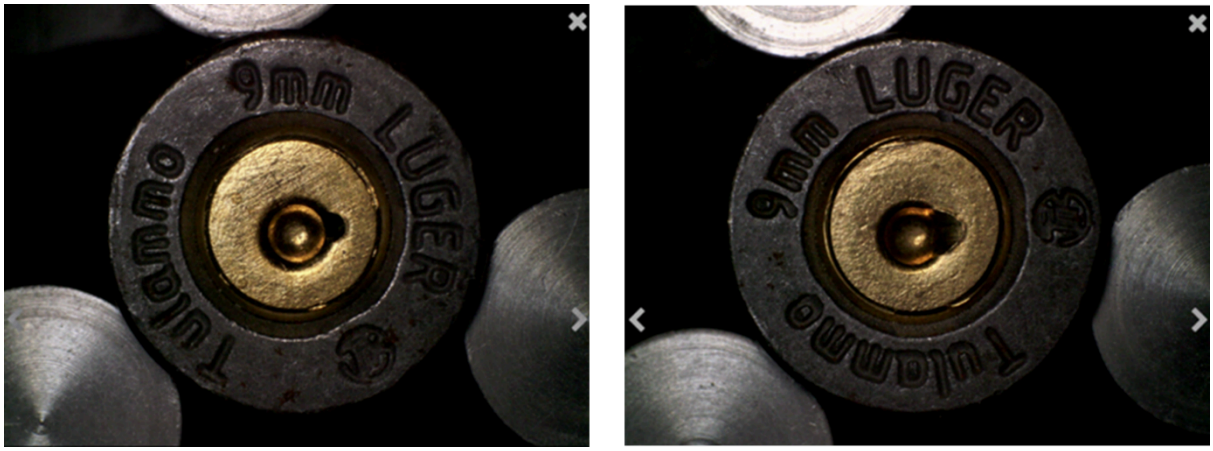


Figure 10: image of the two cartridge cases used for breech face pattern comparisons. Image on the left is ADCH and the image on the right is BMWT.

and saved. Then that same cartridge case was changed to another breech face pattern and orientation and this process continued until all breech face patterns (granular, parallel, crosshatch, circular, arch, and smooth) had been compared to each other. After all CSA Triage reports had been conducted, viewed, and saved, a spreadsheet was created to illustrate the results.

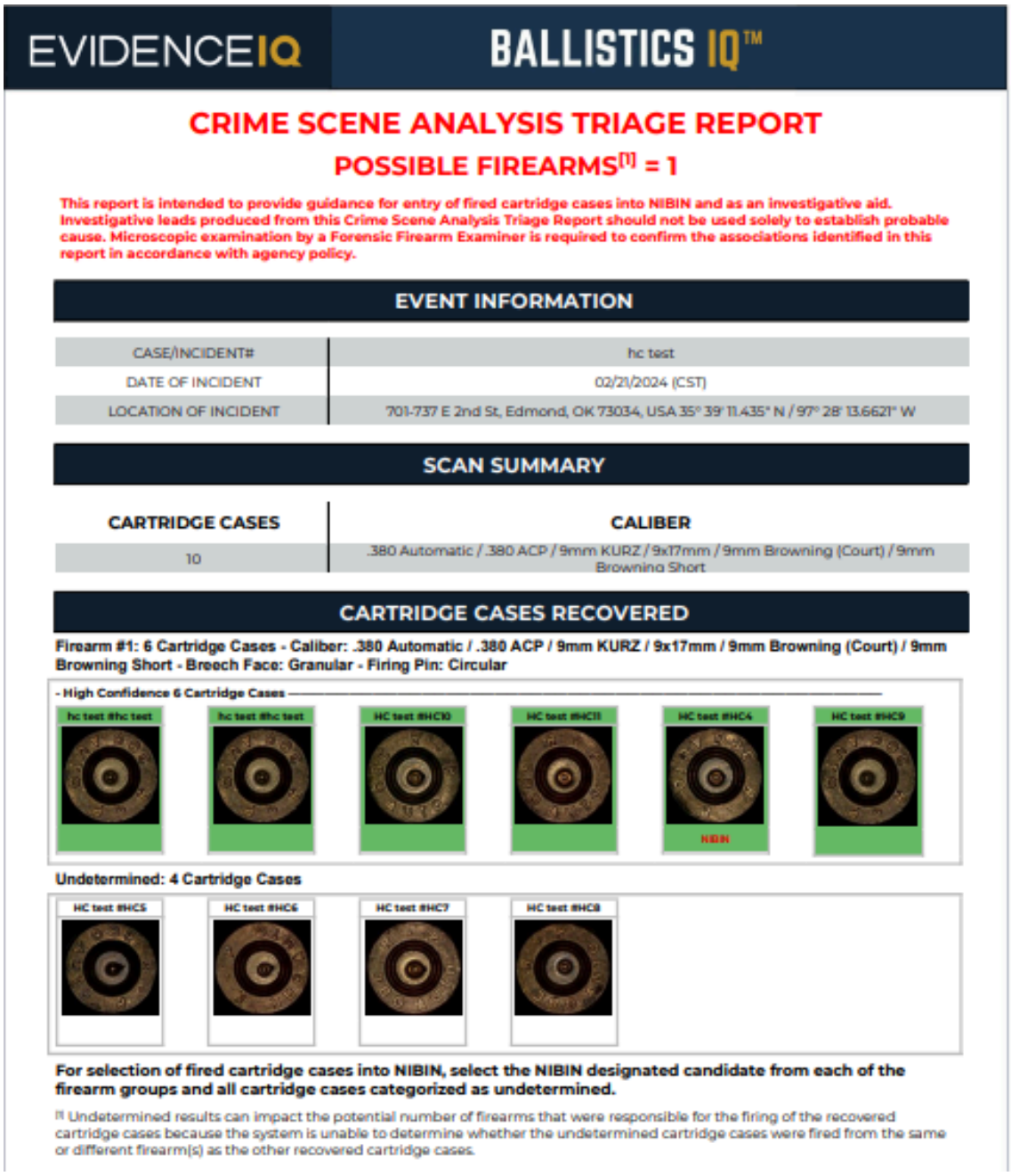
Overall Triage Performance

CSA Reports:

After ensuring that all three hundred (300) cartridge cases were uploaded into BIQ's cloud, a total of seventy-two (72) CSA Triage reports were conducted. The first (1st) CSA Triage report conducted was for all three hundred (300) cartridge cases. The purpose of a CSA Triage report was to compare the various cartridge cases by a proprietary algorithm that was developed by Evidence IQ, which gives the results. The CSA Triage report will place the cartridge cases into three (3) distinct categories: high confidence, low confidence, and undetermined along with showing the number of possible firearms involved. *See Figure 11*. High confidence indicates that the cartridge casings have sufficient agreement, low confidence states that the cartridge cases have some of the same characteristics, and undetermined means that the algorithm does not have enough characteristics to group a cartridge case with others from the same firearm.

After the CSA Triage report involving the three hundred (300) cartridge cases had been saved, seven (7) additional CSA Triage reports were conducted for each firearm. One (1) CSA Triage report was conducted for each of the six ammunition brands within a specific firearm model. For example, with the HiPoint C9, six (6) CSA Triage reports were conducted using Wolf, Maxx Tech, Blazer, CCI, Remington, and Winchester ammunition. After each firearm model had six (6) CSA Triage reports, one (1) CSA Triage report was conducted for all thirty (30) cartridge cases within that specific firearm. Each CSA Triage report was then viewed to ensure that the results in each of the ten (10) CSA Triage reports displayed the same groupings as the all three hundred (300) CSA Triage report. When making the comparison, it became clear that the BIQ Triage grouped some cartridge cases together that were not originally together. Therefore, two (2) more CSA Triage reports were conducted to see if the BIQ Triage would still

group those selected cartridge cases together like it did with the three hundred (300) cartridge cases. One (1) CSA Triage report consisted of sixty (60) cartridge cases, while the other CSA Triage report consisted of ninety (90) cartridge cases. These two CSA Triage reports were then viewed and saved.



EVIDENCEIQ BALLISTICS IQ™

CRIME SCENE ANALYSIS TRIAGE REPORT

POSSIBLE FIREARMS[1] = 1

This report is intended to provide guidance for entry of fired cartridge cases into NIBIN and as an investigative aid. Investigative leads produced from this Crime Scene Analysis Triage Report should not be used solely to establish probable cause. Microscopic examination by a Forensic Firearm Examiner is required to confirm the associations identified in this report in accordance with agency policy.

EVENT INFORMATION

CASE/INCIDENT#	hc test
DATE OF INCIDENT	02/21/2024 (CST)
LOCATION OF INCIDENT	701-737 E 2nd St, Edmond, OK 73034, USA 35° 39' 11.435" N / 97° 28' 13.6621" W

SCAN SUMMARY

CARTRIDGE CASES	CALIBER
10	.380 Automatic / .380 ACP / 9mm KURZ / 9x17mm / 9mm Browning (Court) / 9mm Browning Short

CARTRIDGE CASES RECOVERED

Firearm #1: 6 Cartridge Cases - Caliber: .380 Automatic / .380 ACP / 9mm KURZ / 9x17mm / 9mm Browning (Court) / 9mm Browning Short - Breech Face: Granular - Firing Pin: Circular

- High Confidence 6 Cartridge Cases

hc test #hc test | hc test #hc test | HC test #HC10 | HC test #HC11 | HC test #HC4 | HC test #HC9

NIBIN

Undetermined: 4 Cartridge Cases

HC test #HC5 | HC test #HC6 | HC test #HC7 | HC test #HC8

For selection of fired cartridge cases into NIBIN, select the NIBIN designated candidate from each of the firearm groups and all cartridge cases categorized as undetermined.

[1] Undetermined results can impact the potential number of firearms that were responsible for the firing of the recovered cartridge cases because the system is unable to determine whether the undetermined cartridge cases were fired from the same or different firearm(s) as the other recovered cartridge cases.

Figure 11: image of CSA Triage report showing high confidence and undetermined cartridge cases and number of possible firearms.

Data Analysis

RStudio is software that has the capability to visualize and analyze data. The first (1st) step on RStudio was to create a pairwise comparison data matrix using the data from the BIQ triage algorithm. Following data organization, plots were created for analysis of the BIQ algorithm outputs.

Results/Discussion

Metadata Effects

Edge Check:

When doing the edge check, a total of forty-six (46) cartridge cases were adjusted. Thirty-five (35) cartridge cases were made smaller, and eleven (11) cartridge cases were made larger. The firearms that the cartridge cases were adjusted were Smith and Wesson M&P9, Springfield XD9, SCCY CPX, Taurus PT92, Beretta 92FS, Glock 19, Ruger P89, Ruger LC9, Smith and Wesson SD9VE, and HiPoint C9. With that, two hundred fifty-four (254) cartridge cases were not adjusted. *Refer to Figure 7.*

Rotation Effects:

To address the first (1st) question asked under the rotation effects subcategory under the experimental design:

- Question 1: If the parallel marks are changed from left-right to up-down, can the BIQ Triage recognize that the cartridge cases originated from the same firearm regardless of orientation?

The results were that the BIQ Triage could successfully recognize that the five (5) cartridge cases utilized originated from the HiPoint C9 at a high confidence level, regardless of the orientation of the parallel marks. *See the results in Figures 12-15.*

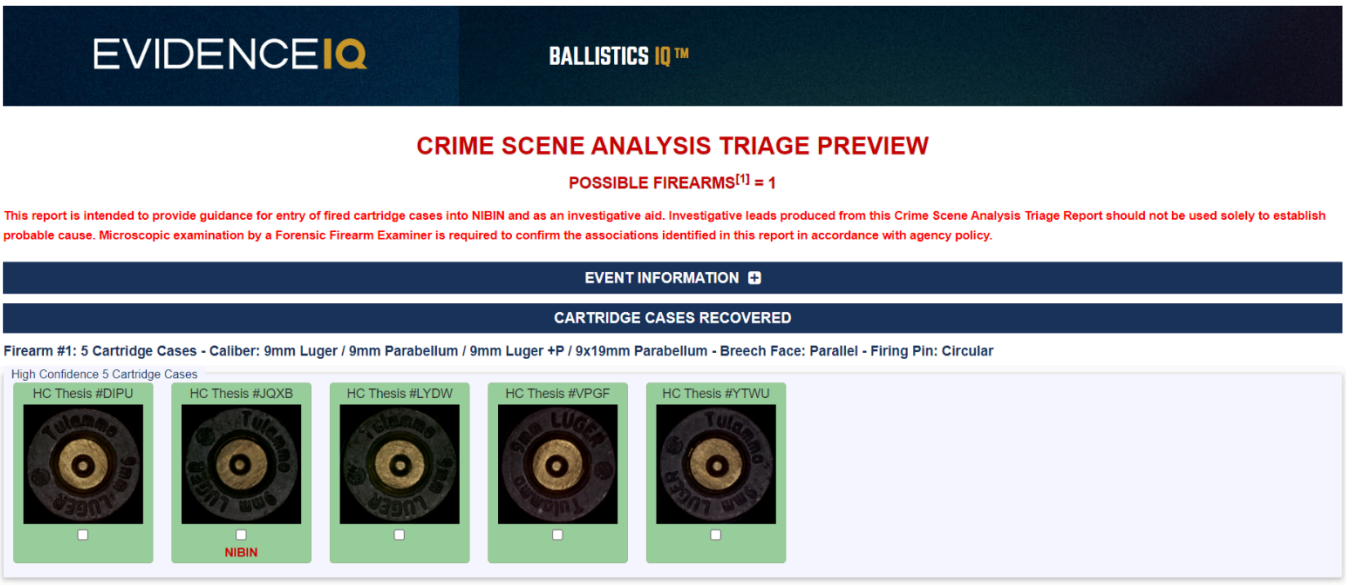


Figure 12: image of the results from the rotation effects during the experimental design. Utilized are five (5) cartridge cases with Maxx Tech ammunition.

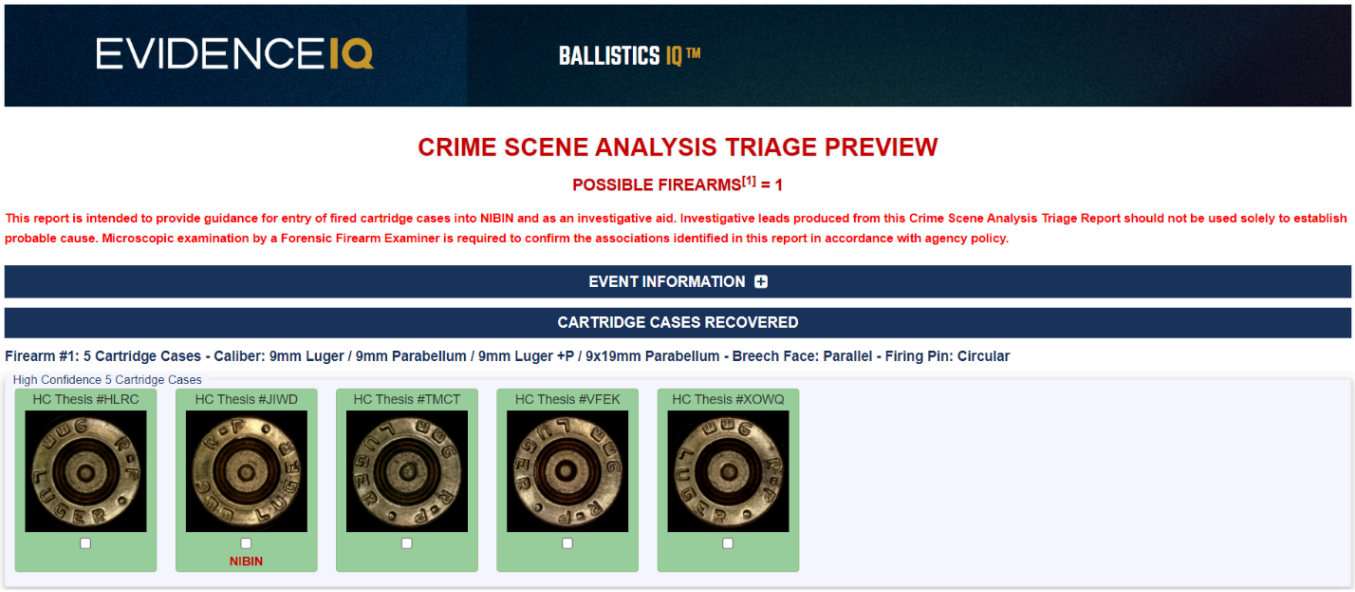


Figure 13: image of the results from the rotation effects during the experimental design. Utilized are five (5) cartridge cases with Remington ammunition.

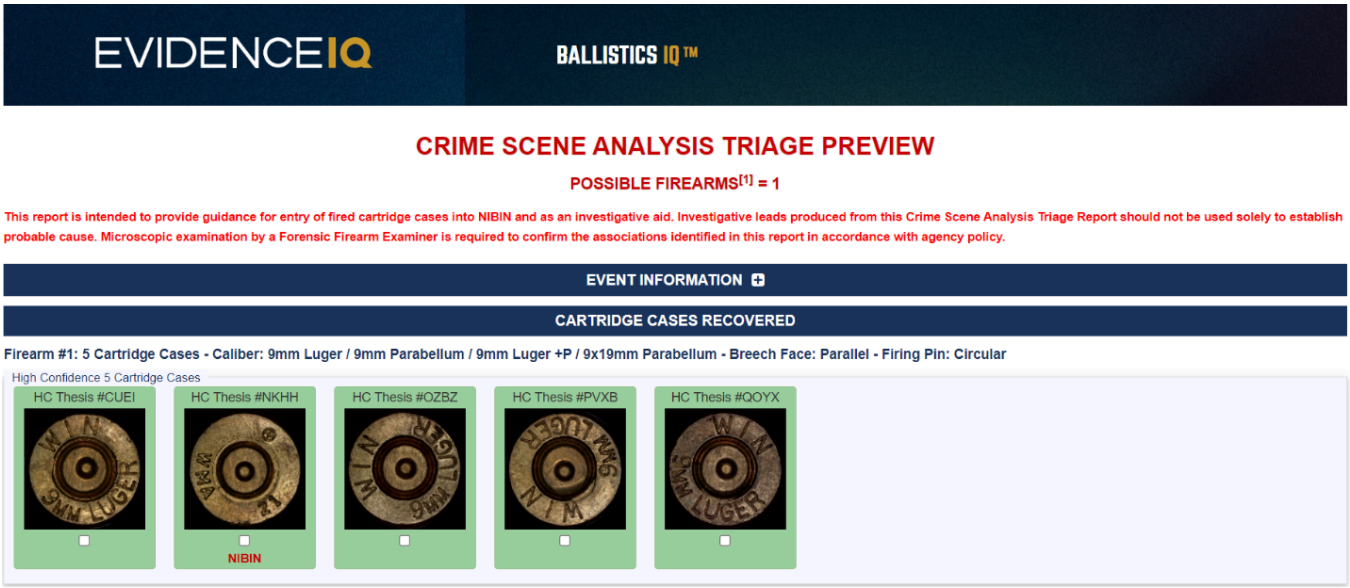


Figure 14: image of the results from the rotation effects during the experimental design. Utilized are five (5) cartridge cases with Winchester ammunition.

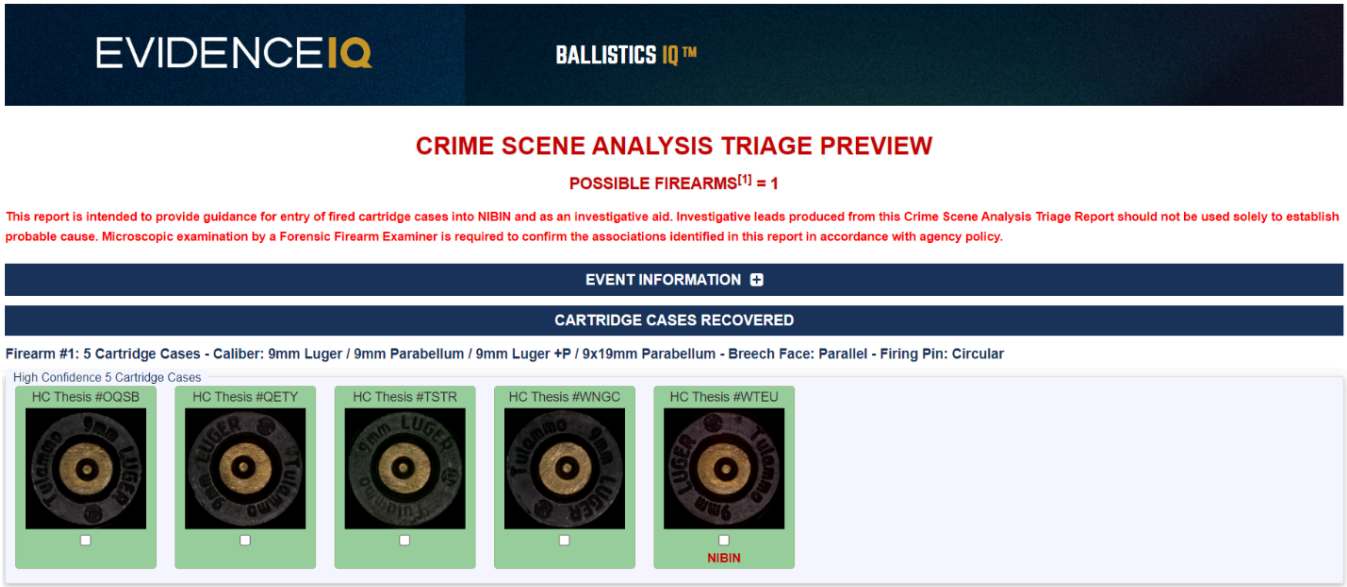


Figure 15: image of the results from the rotation effects during the experimental design. Utilized are five (5) cartridge cases with Wolf ammunition.

To address the second (2nd) question asked under the rotation effects subcategory under the experimental design:

- Question 2: If the drag mark and ejector mark are rotated 180º, can the BIQ Triage recognize that the cartridge cases originated from the same firearm regardless of orientation?

The results were that the BIQ Triage could successfully recognize that the ten (10) cartridge cases originated from the Smith & Wesson M&P9 at a high confidence level, regardless of the orientation of the drag mark and ejector mark. *See Figure 16.*

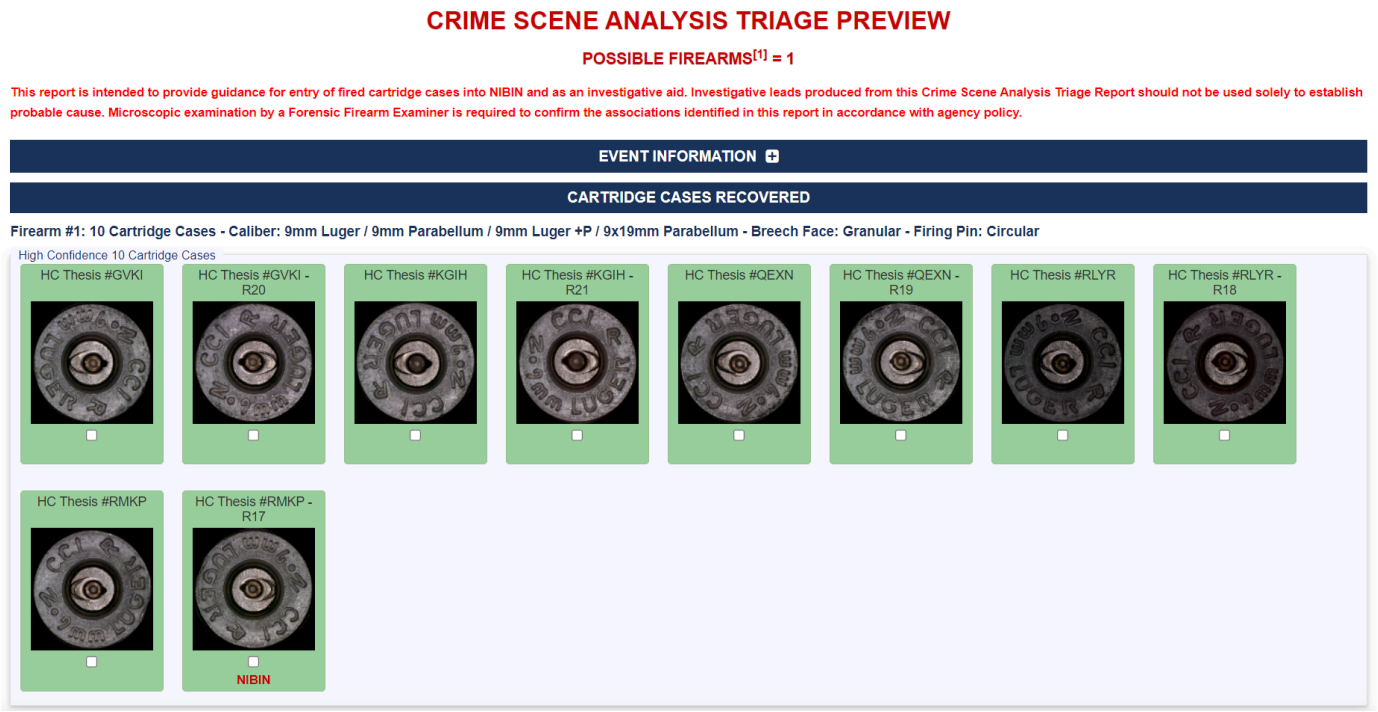


Figure 16: image of the results from the rotation effects during the experimental design. Utilized are ten (10) cartridge cases with CCI ammunition.

Recovered vs Test-Fired:

The overall results for the recovered vs test-fired is that the BIQ triage can successfully identify that the cartridge cases originated from the same firearm at a high confidence level

regardless of recovered or test-fired as the category. For the first (1st) section of testing how the BIQ Triage differentiated between recovered and test-fired, the HiPoint C9 and Smith & Wesson M&P9 were used. These two (2) firearms were utilized because they had cartridge cases that had been re-scanned for another part of the research. When interpreting the results for the HiPoint C9 firearm using Wolf ammunition, all cartridge cases originated from one (1) firearm at a high confidence regardless of them being categorized as test-fired or recovered. *See Figure 17.* Similar to the results from the HiPoint C9 firearm and Wolf ammunition, when interpreting the results for this firearm using Maxx Tech ammunition, all cartridge cases originated from one (1) firearm at a high confidence, also regardless of them being categorized as test-fired or recovered. *See Figure 18.*

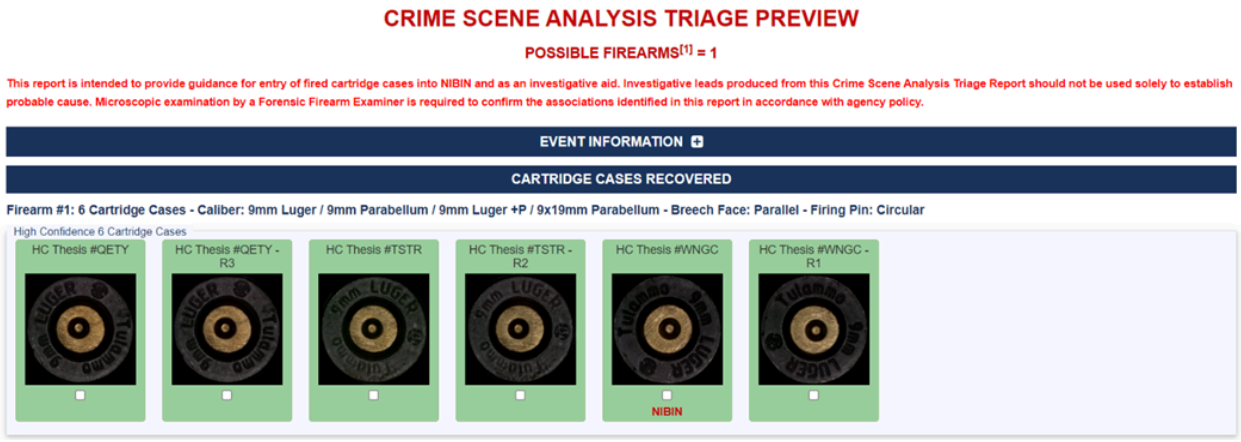


Figure 17: image of the results from the recovered vs test-fired section during the experimental design. Utilized are three (3) recovered and test-fired cartridge cases with Wolf ammunition from a HiPoint C9 firearm.

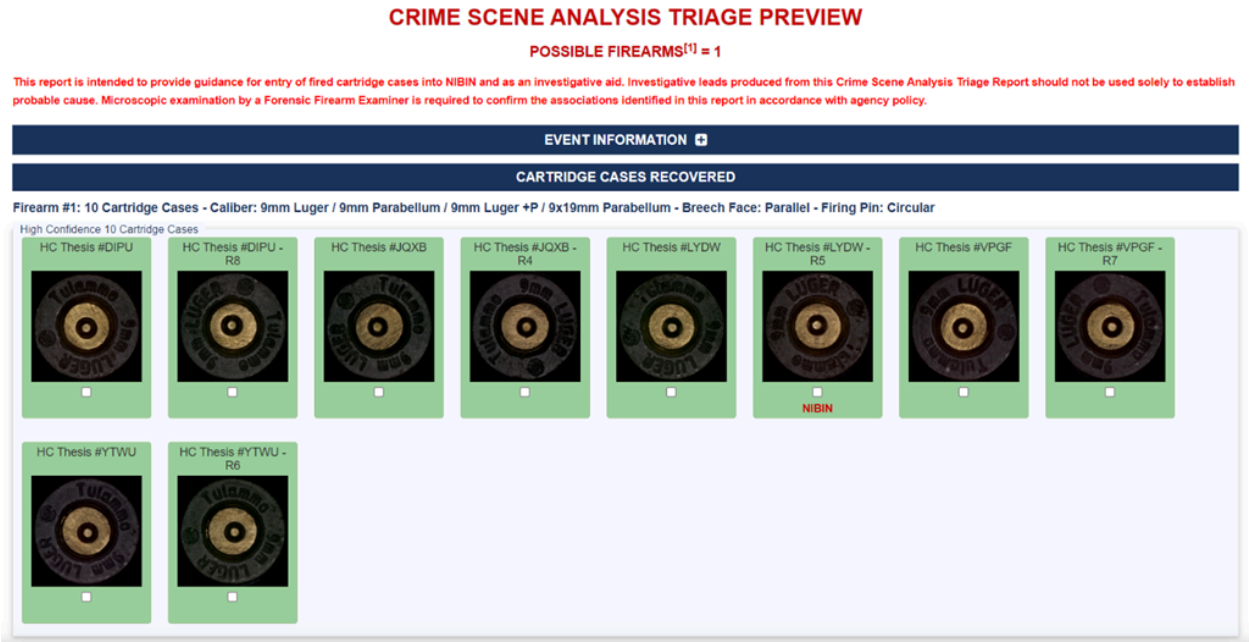


Figure 18: image of the results from the recovered vs test-fired section during the experimental design. Utilized are ten (10) recovered and test-fired cartridge cases with Maxx Tech ammunition from a HiPoint C9 firearm.

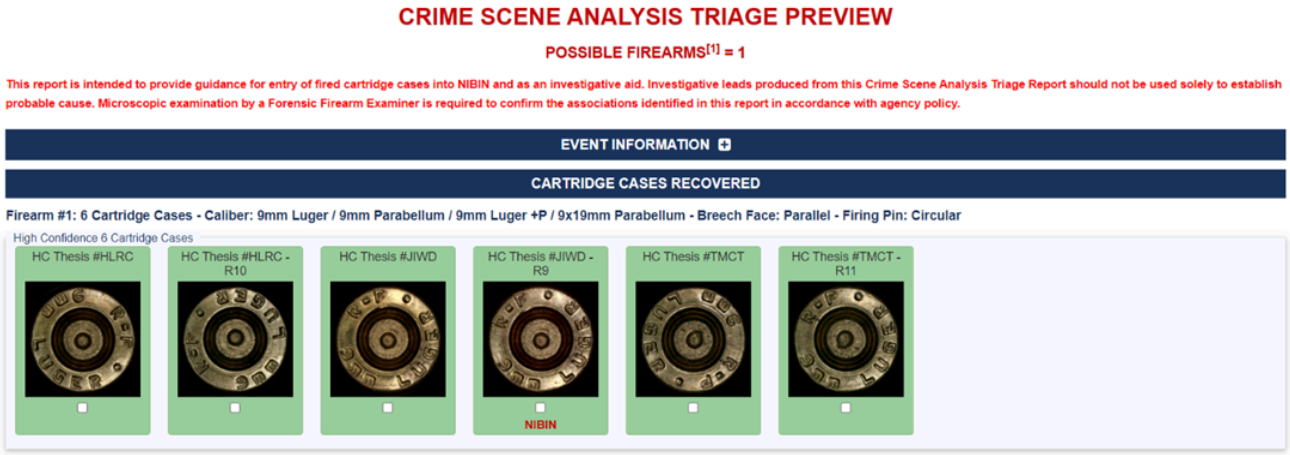


Figure 19: image of the results from the recovered vs test-fired section during the experimental design. Utilized are six recovered and test-fired cartridge cases with Remington ammunition from a HiPoint C9 firearm.

The next ammunition brand tested using the HiPoint C9 firearm was Remington. When interpreting these results, it was abundantly clear that the BIQ Triage successfully identified that all cartridge cases originated from one (1) firearm at a high confidence regardless of them being categorized as test-fired or recovered. *See Figure 19.* Winchester ammunition was the last ammunition brand tested using the HiPoint C9 firearm. Like the above results, the BIQ Triage concluded that all cartridge cases originated from one (1) firearm at a high confidence regardless of them being categorized as test-fired or recovered. *See Figure 20.*

Figure 20: image of the results from the recovered vs test-fired section during the experimental design. Utilized are ten (10) recovered and test-fired cartridge cases with Winchester ammunition.

Unlike the HiPoint C9 firearm, the Smith & Wesson M&P9 firearm was only tested with one (1) ammunition brand, which was CCI. As a brief refresher, CCI ammunition was the only ammunition brand re-scanned for the Smith & Wesson M&P9 firearm which is why only this ammunition brand was tested for this section. When analyzing the results, the BIQ Triage concluded that all cartridge cases originated from one (1) firearm at a high confidence. *See Figure 21.*

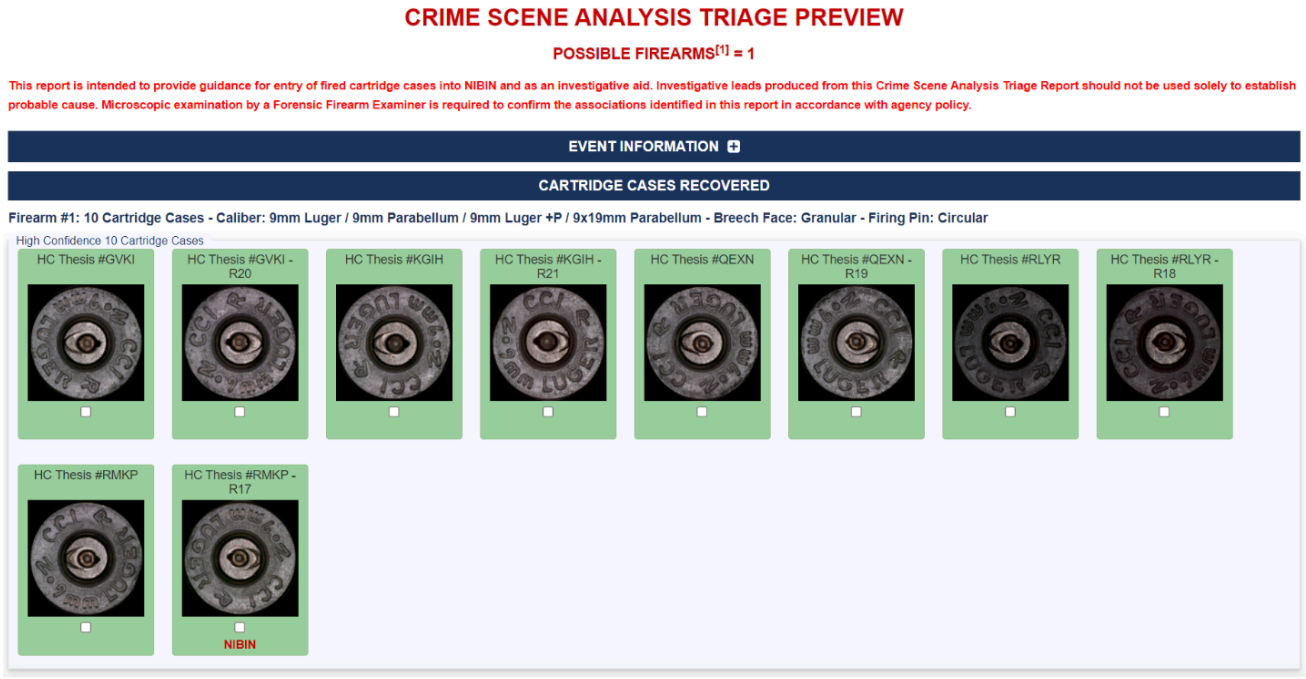


Figure 21: image of the results from the recovered vs test-fired section during the experimental design. Utilized are ten (10) recovered and test-fired cartridge cases with CCI ammunition.

The second (2nd) section of testing how the BIQ Triage differentiated between recovered and test-fired utilized the Glock 19 and Smith & Wesson SD9VE firearms with Winchester ammunition. Both firearms were selected because each is manufactured in different ways and have different physical appearances. These firearms were also utilized because in order to effectively test the BIQ Triage, one must do so by using cartridge cases that originated from two (2) firearms. Winchester ammunition was selected based on random selection. Two (2) cartridge cases were selected for this analysis, SONI and ZEBO. Both cartridge cases were first (1st) categorized as test-fired and the metadata for where both cartridge cases originated from was the Smith & Wesson SD9VE firearm. The BIQ Triage concluded that SONI derived from one (1) firearm at a high confidence and ZEBO derived from a second (2nd) firearm at a high confidence, which is correct. This illustrates that the BIQ Triage focused on the characteristics that were present on the cartridge case and not the metadata. *See Figure 22.* After changing SONI and ZEBO from test-fired to recovered, the BIQ Triage still concluded that SONI derived from one (1) firearm at a high confidence and ZEBO derived from a second (2nd) firearm at a high confidence, which is correct. *See Figure 23.*

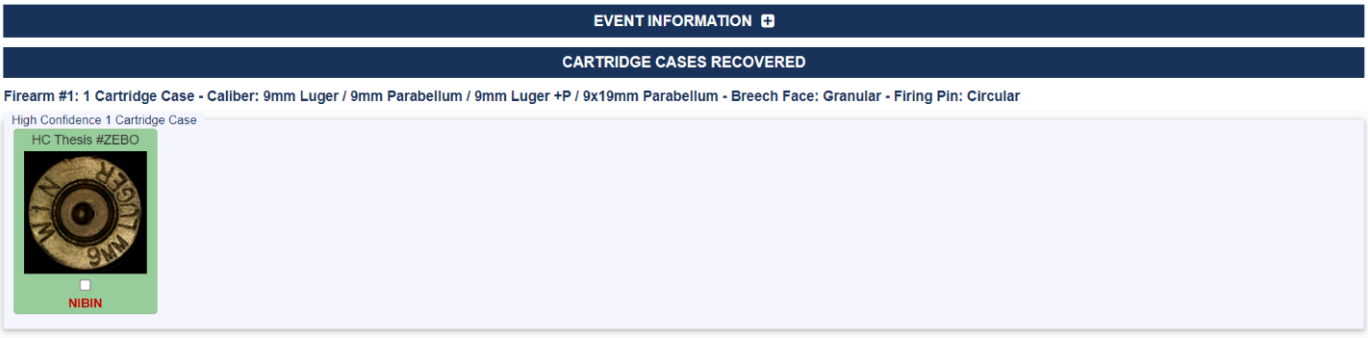


Figure 22: image of the results from the recovered vs test-fired during the experimental design. Utilized are two (2) test-fired cartridge cases, SONI from Glock 19 and ZEBO from Smith & Wesson SD9VE.

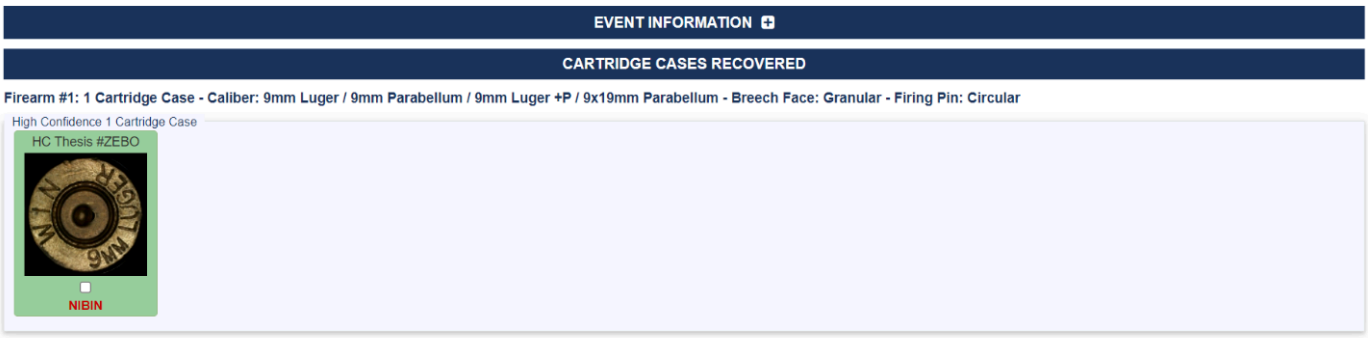


Figure 23: image of the results from the recovered vs test-fired during the experimental design. Utilized are two (2) recovered cartridge cases, SONI from Glock 19 and ZEBO from Smith & Wesson SD9VE.

Breech Face Patterns:

When testing the BIQ Triage algorithm regarding its metadata for the breech face pattern, a Ruger LC9 and Maxx Tech ammunition was used. As a refresher, testing of this factor was conducted to determine if the BIQ Triage automatically compared one breech face pattern to another. This is an important factor to test because if the BIQ Triage cannot recognize the different breech face patterns, then there is a possibility it can group incorrect cartridge cases. The Ruger LC9 firearm and ammunition brand were randomly selected. Two (2) cartridge cases were selected, ADCH and BMWT to represent a breech face pattern. *See Table 3.* As seen in table 2, the cartridge case labeled as BMWT had a breech face pattern of parallel with a type 3 orientation and the cartridge case labeled as ADCH had a breech face pattern of granular with a type 7 orientation. The CSA Triage report revealed that both cartridge cases, regardless of breech face pattern and orientation type derived from one (1) firearm at a high confidence. The BIQ Triages conclusion ended up being correct as these two cartridge cases did derive from one (1) firearm. Several more tests were conducted using the same firearm, ammunition brand, and cartridge cases. The only components that changed throughout the process were the breech face pattern and orientation type. The overall results for the comparison of the various breech face patterns are that the BIQ Triage will compare across the different breech pattern types, with the exception of a five (5). The five (5) breech face patterns that changed the BIQ Triage conclusion from one (1) firearm at a high confidence to two (2) firearms at a high confidence were: Arch vs Parallel, Circular vs Parallel, Arch vs Circular, Arch vs Crosshatch, and Crosshatch vs Circular. *Refer to Table 3.*

Table 3: Comparison results from the breech face patterns section during the experimental design. Utilized are two (2) cartridge cases, ADCH and BMWT, both from a Ruger LC9 and Maxx Tech ammunition.

	Firearm Used	Ammo Type	BMWT Cartridge Case	ADCH Cartridge Case	Results	Correct Conclusion (yes/no)
Granular vs...	Ruger LC9	Maxx Tech	Parallel, type 3 orientation	Granular, type 7 orientation	1 gun, high confidence	Yes
	Ruger LC9	Maxx Tech	Arched, type 1 orientation	Granular, type 7 orientation	1 gun, high confidence	Yes
	Ruger LC9	Maxx Tech	Circular, type 5 orientation	Granular, type 7 orientation	1 gun, high confidence	Yes
	Ruger LC9	Maxx Tech	Crosshatch, type 5 orientation	Granular, type 7 orientation	1 gun, high confidence	Yes
	Ruger LC9	Maxx Tech	Smooth, type 5 orientation	Granular, type 7 orientation	1 gun, high confidence	Yes
Smooth vs...	Ruger LC9	Maxx Tech	Arched, type 1 orientation	Smooth, type 7 orientation	1 gun, high confidence	Yes
	Ruger LC9	Maxx Tech	Circular, type 5 orientation	Smooth, type 7 orientation	1 gun, high confidence	Yes
	Ruger LC9	Maxx Tech	Crosshatch, type 5 orientation	Smooth, type 7 orientation	1 gun, high confidence	Yes
	Ruger LC9	Maxx Tech	Parallel, type 3 orientation	Smooth, type 7 orientation	1 gun, high confidence	Yes
	Ruger LC9	Maxx Tech	Granular, type 5 orientation	Smooth, type 7 orientation	1 gun, high confidence	Yes
Parallel vs...	Ruger LC9	Maxx Tech	Arch, type 1 orientation	Parallel, type 3 orientation	2 guns, high confidence	No
	Ruger LC9	Maxx Tech	Circular, type 5 orientation	Parallel, type 3 orientation	2 guns, high confidence	No
	Ruger LC9	Maxx Tech	Crosshatch, type 5 orientation	Parallel, type 3 orientation	1 gun, high confidence	Yes
	Ruger LC9	Maxx Tech	Smooth, type 5 orientation	Parallel, type 3 orientation	1 gun, high confidence	Yes
	Ruger LC9	Maxx Tech	Granular, type 5 orientation	Parallel, type 3 orientation	1 gun, high confidence	Yes
Arch vs...	Ruger LC9	Maxx Tech	Arch, type 1 orientation	Circular, type 7 orientation	2 guns, high confidence	No
	Ruger LC9	Maxx Tech	Arch, type 1 orientation	Crosshatch, type 7 orientation	2 guns, high confidence	No
	Ruger LC9	Maxx Tech	Arch, type 1 orientation	Granular, type 7 orientation	1 gun, high confidence	Yes
	Ruger LC9	Maxx Tech	Arch, type 1 orientation	Smooth, type 7 orientation	1 gun, high confidence	Yes
	Ruger LC9	Maxx Tech	Arch, type 1 orientation	Parallel, type 3 orientation	2 guns, high confidence	No
Circular vs...	Ruger LC9	Maxx Tech	Crosshatch, type 5 orientation	Circular, type 7 orientation	2 guns, high confidence	No
	Ruger LC9	Maxx Tech	Smooth, type 5 orientation	Circular, type 7 orientation	1 gun, high confidence	Yes
	Ruger LC9	Maxx Tech	Parallel, type 3 orientation	Circular, type 7 orientation	2 guns, high confidence	No
	Ruger LC9	Maxx Tech	Arched, type 1 orientation	Circular, type 7 orientation	2 guns, high confidence	No
	Ruger LC9	Maxx Tech	Granular, type 5 orientation	Circular, type 7 orientation	1 gun, high confidence	Yes
Crosshatch vs...	Ruger LC9	Maxx Tech	Crosshatch, type 5 orientation	Granular, type 7 orientation	1 gun, high confidence	Yes
	Ruger LC9	Maxx Tech	Crosshatch, type 5 orientation	Smooth, type 7 orientation	1 gun, high confidence	Yes
	Ruger LC9	Maxx Tech	Crosshatch, type 5 orientation	Parallel, type 3 orientation	1 gun, high confidence	Yes
	Ruger LC9	Maxx Tech	Arch, type 1 orientation	Crosshatch, type 7 orientation	2 guns, high confidence	No
	Ruger LC9	Maxx Tech	Crosshatch, type 5 orientation	Circular, type 7 orientation	2 guns, high confidence	No

Ballistics IQ Triage Performance

The first (1st) plot created was a scatterplot for all three hundred (300) cartridge cases utilizing the conclusions received from the BIQ CSA Triage Report. *See Figure 24.* This scatterplot illustrates the overall performance of the BIQ Triage using all three hundred (300) cartridge cases. The three (3) colors (Green, Blue, and Red) within this plot represent the three (3) BIQ confidence levels (high, low and undetermined, respectively). Based on the results in this plot, the BIQ triage algorithm showed that all three hundred (300) cartridge cases originated

from seven (7) firearms rather than the ground truth which was ten (10) firearms. *Refer to Figure 24.*

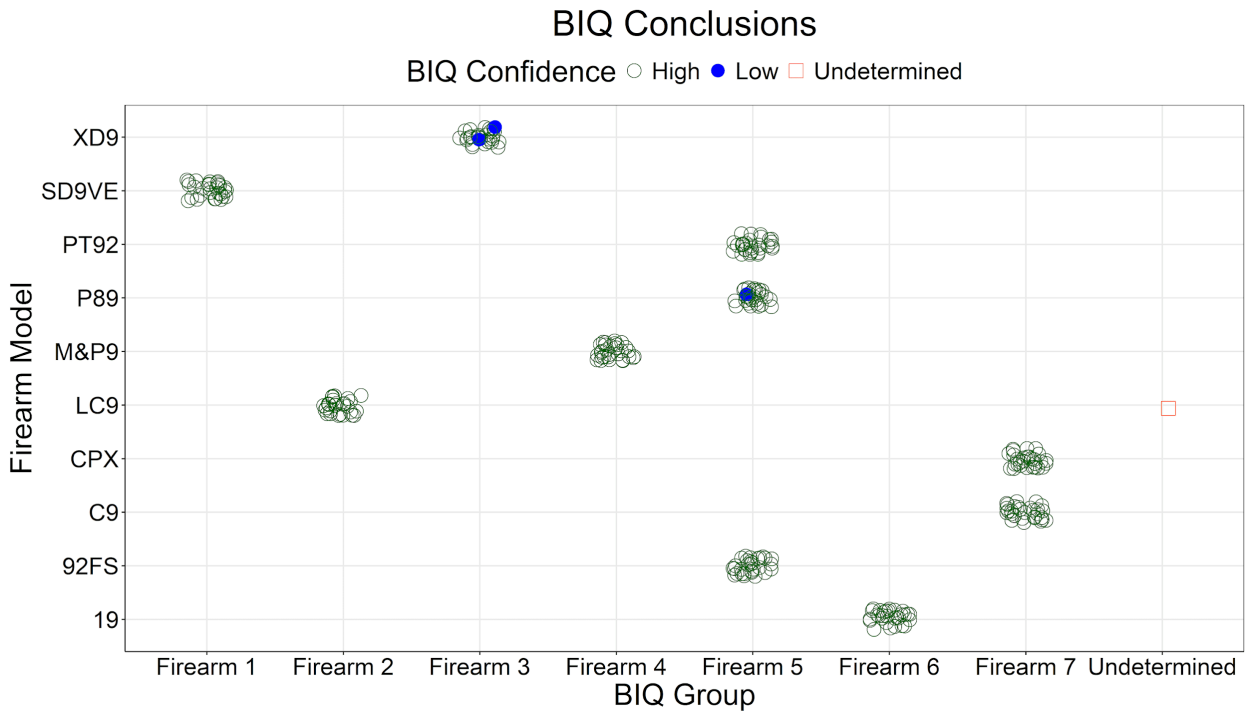


Figure 24: Scatterplot representing all three hundred (300) cartridge cases using the conclusions received from the BIQ CSA Triage Report.

To elaborate further, when viewing the results from Firearm 1, thirty (30) cartridge cases were correctly identified as belonging to this firearm at a high confidence. However, when analyzing the results for Firearm 2, twenty-nine (29) cartridge cases were correctly identified as belonging to this firearm at a high confidence, but the last cartridge case was placed in the "Undetermined" category. For Firearm 3, thirty (30) cartridge cases were correctly identified as originating from this firearm; however, twenty-eight (28) cartridge cases were identified at a high confidence, while the other two (2) cartridge cases were identified as low confidence. When analyzing the results for Firearm 4, the BIQ Triage correctly identified that thirty (30) cartridge cases originated from this firearm at a high confidence level. *Refer to Figure 24.* For Firearm 5,

the BIQ Triage concluded that a total of ninety (90) cartridge cases derived from one (1) firearm. *See Figure 25.* The BIQ Triage concluded that thirty (30) cartridge cases from the Taurus PT92 stemmed from this firearm at a high confidence. However, the BIQ Triage also concluded that thirty (30) cartridge cases from the Ruger P89 stemmed from this firearm with twenty-nine (29) cartridge cases at a high confidence and one (1) cartridge case at a low confidence. In addition to this, the BIQ Triage also concluded that thirty (30) cartridge cases from a Beretta 92FS stemmed from this firearm at a high confidence. All in all, the results for Firearm 5 state that the BIQ Triage concluded that ninety (90) cartridge cases originated from the same firearm, which is incorrect. When viewing the results for Firearm 6, the BIQ Triage concluded that thirty (30) cartridge cases derived from this firearm at a high confidence. When viewing the results for the last firearm, Firearm 7, the BIQ Triage concluded that a total of sixty (60) cartridge cases derived from this firearm. *See Figure 26.* The BIQ Triage concluded that thirty (30) cartridge cases from the SCCY CPX derived from this firearm at a high confidence. The BIQ Triage also concluded that thirty (30) cartridge cases from the HiPoint C9 also derived from this firearm at a high confidence. This resulted in a total of sixty (60) cartridge cases belonging to Firearm 7, which is incorrect. *Refer to Figure 24.*

Figure 25: Image of three (3) cartridge cases, one from each firearm involved in the CSA Triage report for Firearm #5. The left cartridge case is labeled as HYEQ in the BIQ database and originated from a Taurus PT92. The middle cartridge case is labeled as NLAW in the BIQ database and originated from a Beretta 92FS. The right cartridge case is labeled as SOKE in the BIQ database and originated from a Ruger P89.

Figure 26: Image of two (2) cartridge cases, one from each firearm involved in the CSA Triage report for Firearm #7. The cartridge case on the left is labeled as GDYL in the BIQ database and originated from a SCCY CPX. The cartridge case on the right is labeled as VFEK in the BIQ database and originated from a HiPoint C9.

Due to the BIQ Triage incorrectly grouping cartridge cases for Firearms 5 and 7, two (2) additional CSA Triage reports were conducted independently. These additional reports were conducted to determine if the BIQ Triage could correctly group the cartridge cases once separated from the three hundred (300) grouping. One (1) CSA Triage report was for Firearm 5 which had ninety (90) cartridge cases. The second (2nd) CSA Triage report was for Firearm 7 which had sixty (60) cartridge cases. Despite isolating the cartridge cases from the complete group of three hundred (300) in the CSA Triage report, the BIQ Triage algorithm still categorized all cartridge cases as belonging to the same firearm. It was hypothesized that the BIQ Triage grouped the selected cartridge cases within the two firearms because the Taurus PT92 and Beretta 92FS are manufactured using the same process (Monturo, 2019, p. 118). Another question raised regarding the incorrect grouping of cartridge cases by the BIQ Triage was whether three hundred (300) cartridge cases were too many for the BIQ to compare. With that, two (2) additional tests were conducted to address this question. The first test consisted of the ninety (90) cartridge cases belonging to "Firearm 5". For this firearm, a CSA Triage report was conducted of three (3) cartridge cases, one (1) from each firearm. After the CSA Triage report was analyzed, another CSA Triage report was conducted to include nine (9) cartridge cases, three (3) from each firearm. This process was repeated by adding three (3) cartridge cases each time until the BIQ Triage started to incorrectly group the firearms. It was later determined that the BIQ Triage started to incorrectly group the cartridge cases when being asked to compare seventy-two (72) cartridge cases, or twenty-four (24) from each firearm. The second (2nd) test consisted of sixty (60) cartridge cases from "Firearm 7". For this firearm, a CSA Triage report was conducted of two (2) cartridge cases, one (1) from each firearm. After the CSA Triage report

was analyzed, another CSA Triage report was conducted including four (4) cartridge cases total. This process was repeated, adding two (2) more cartridge cases each time until the BIQ Triage started to incorrectly group the firearms. It was later determined that the BIQ Triage starts to incorrectly group the cartridge cases when comparing forty-four (44) cartridge cases, or twenty-two (22) from each firearm.

Ammunition Effects

The first (1st) box plot illustrates how the different ammunition brands and firearms differ from each other according to BIQ. *See Figure 27.* When analyzing these results, ammunition brands involving Remington and Winchester tended to score lower than 85 on the match group score scale compared to the other ammunition brands. Figure 28 illustrates that most of the match scores belonging to Maxx Tech, Wolf, CCI, and Blazer ammunition tend to score higher than 85. In addition to the different ammunition distribution box plots, another box plot was generated that combined the ten (10) individual box plots representing the same ammunition and firearms. *See Figure 28.* When analyzing these results, Remington and Winchester ammunition brands scored similarly. Among all the ammunition brands in this plot, Wolf ammunition performed the best, with only one outlier. Regardless of the firearm, all the scores provided a similar level of variation to the other brands. However, it is unclear what the scores from the match score group represent and how they contribute to the triage group which leads to questions about whether this could explain why Winchester and Remington ammunition received lower scores compared to other brands.

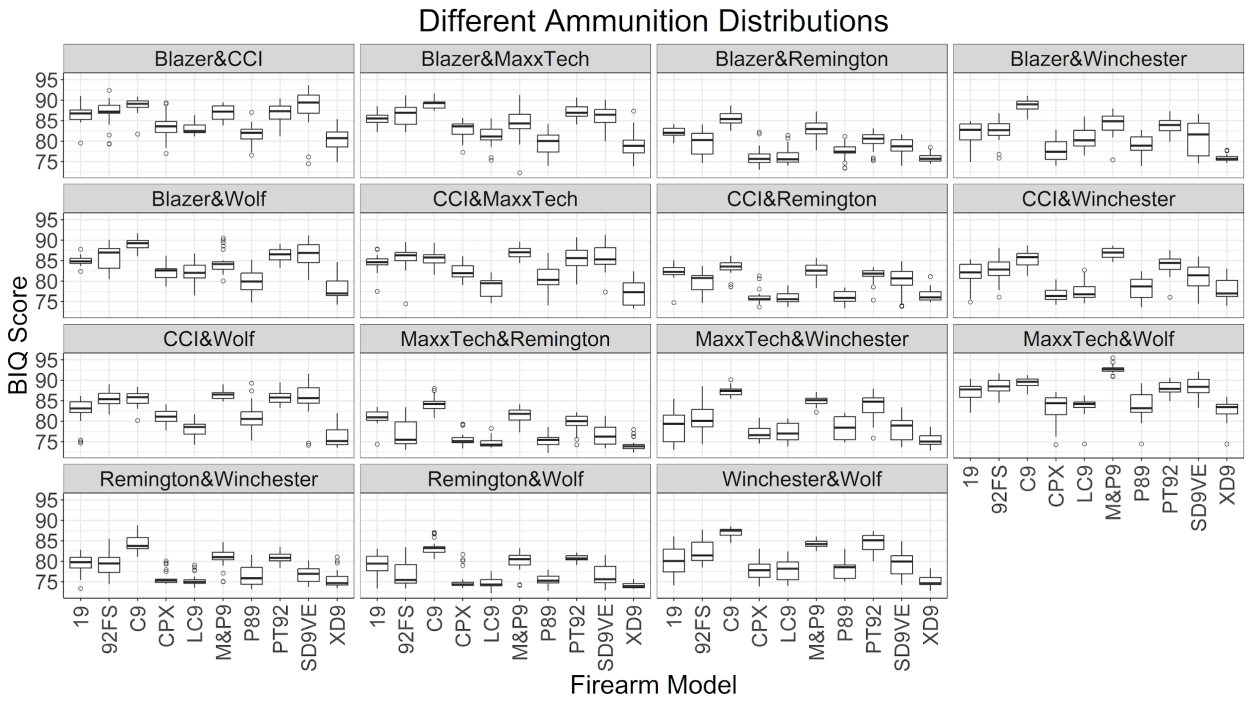


Figure 27: Box plot illustrating how the different ammunition brands and firearms differ from each other. On the x-axis is the firearm model. On the y-axis is the match score received from the BIQ Triage.

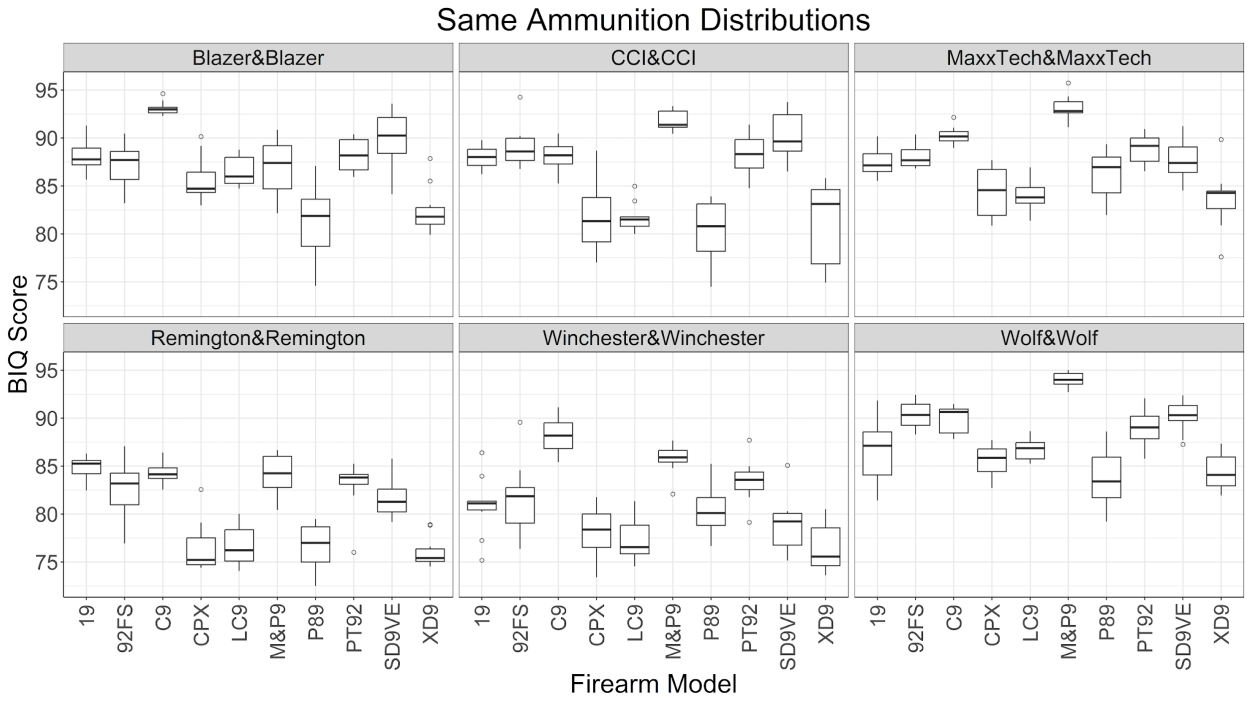


Figure 28: Box plot illustrating a comparison between same ammunition brands and firearms. On the x-axis is the firearm model. On the y-axis is the match score received from the BIQ Triage.

CSA Triage Reports:

After conducting the above CSA Triage reports, sixty (60) additional CSA Triage reports were conducted for each individual firearm. The overall results for the HiPoint C9 are that all thirty (30) cartridge cases originated from the same firearm at a high confidence. When simplifying the results based on ammunition brands, the BIQ Triage stated that regardless of ammunition type selected, all cartridge cases originated from the same firearm at a high confidence. Like the results from the HiPoint C9, all cartridge cases belonging to the Smith & Wesson SD9VE originated from the same firearm at a high confidence. When simplifying these results based on ammunition brands, the BIQ Triage stated that regardless of ammunition type selected, all cartridge cases originated from the same firearm at a high confidence.

Unlike the HiPoint C9 and Smith & Wesson SD9VE firearms, when the Ruger LC9 firearm was given its own CSA Triage report, the results were scattered. For instance, when viewing the CSA Triage report for this firearm, only twenty-nine (29) cartridge cases were grouped together at a high confidence and one (1) cartridge case, FHTF, was undetermined. When simplifying those results based on the various ammunition brands, the BIQ Triage concluded that all cartridge cases from Winchester, Maxx Tech, Blazer, CCI, and Wolf ammunition originated from the same firearm at a high confidence. Remington ammunition on the other hand had scattered results. While four (4) cartridge cases originated from one (1) firearm, three (3) of those cartridge cases were at a high confidence and one (1) cartridge case was at a low confidence. The last cartridge case was concluded as undetermined. *See Figure 29.*

CRIME SCENE ANALYSIS TRIAGE REPORT

POSSIBLE FIREARMS[1] = 1

This report is intended to provide guidance for entry of fired cartridge cases into NIBIN and as an investigative aid. Investigative leads produced from this Crime Scene Analysis Triage Report should not be used solely to establish probable cause. Microscopic examination by a Forensic Firearm Examiner is required to confirm the associations identified in this report in accordance with agency policy.

EVENT INFORMATION

CASE/INCIDENT#	HC Thesis
DATE/TIME OF INCIDENT	06/13/2024 (CST)
LOCATION OF INCIDENT	UNIVERSITY OF CENTRAL OKLAHOMA 35° 39' 27.0216" N / 97° 28' 15.4168" W

SCAN SUMMARY

CARTRIDGE CASES	CALIBER
5	9mm Luger / 9mm Parabellum / 9mm Luger +P / 9x19mm Parabellum

CARTRIDGE CASES RECOVERED

Firearm #1: 4 Cartridge Cases - Caliber: 9mm Luger / 9mm Parabellum / 9mm Luger +P / 9x19mm Parabellum - Breech Face: Granular - Firing Pin: Circular

- High Confidence 3 Cartridge Cases

HC Thesis #SHBH

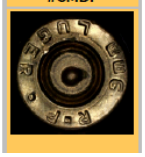
HC Thesis #ZALT

HC Thesis #ZNVU

NIBIN

- Low Confidence 1 Cartridge Case

HC Thesis #CMDF



Undetermined: 1 Cartridge Case

HC Thesis #FHTF

Figure 29: image of five (5) cartridge cases from Remington ammunition that were shot using the Ruger LC9 within this study. Three (3) cartridge cases, SHBH, ZALT, and ZNVU, originated from the same firearm at a high confidence, one (1) cartridge case, CMDF, as low confidence. The last cartridge case, FHTF, was labeled as undetermined.

Similar to the results for the Ruger LC9, the results for the CSA Triage report using the Ruger P89 firearm were also scattered. When viewing the CSA Triage report, twenty-nine (29) cartridge cases originated from the same firearm at a high confidence; however, one (1) cartridge case, MOWG, was at a low confidence. When simplifying the results based on the different ammunition brands, the BIQ Triage concluded that the cartridge cases belonging to Winchester, Maxx Tech, Blazer, CCI, and Wolf ammunition originated from the same firearm at a high confidence. However, when viewing the Remington ammunition, the BIQ Triage concluded that two (2) cartridge cases originated from the same firearm at a high confidence, but the other three (3) cartridge cases were low confidence. *See Figure 30.*

CRIME SCENE ANALYSIS TRIAGE REPORT

POSSIBLE FIREARMS[1] = 1

This report is intended to provide guidance for entry of fired cartridge cases into NIBIN and as an investigative aid. Investigative leads produced from this Crime Scene Analysis Triage Report should not be used solely to establish probable cause. Microscopic examination by a Forensic Firearm Examiner is required to confirm the associations identified in this report in accordance with agency policy.

EVENT INFORMATION

CASE/INCIDENT#	HC Thesis
DATE/TIME OF INCIDENT	07/17/2024 (CST)
LOCATION OF INCIDENT	UNIVERSITY OF CENTRAL OKLAHOMA 35° 39' 27.0216" N / 97° 28' 15.4168" W

SCAN SUMMARY

CARTRIDGE CASES	CALIBER
5	9mm Luger / 9mm Parabellum / 9mm Luger +P / 9x19mm Parabellum

CARTRIDGE CASES RECOVERED

Firearm #1: 5 Cartridge Cases - Caliber: 9mm Luger / 9mm Parabellum / 9mm Luger +P / 9x19mm Parabellum - Breech Face: Granular - Firing Pin: Circular

- High Confidence 2 Cartridge Cases

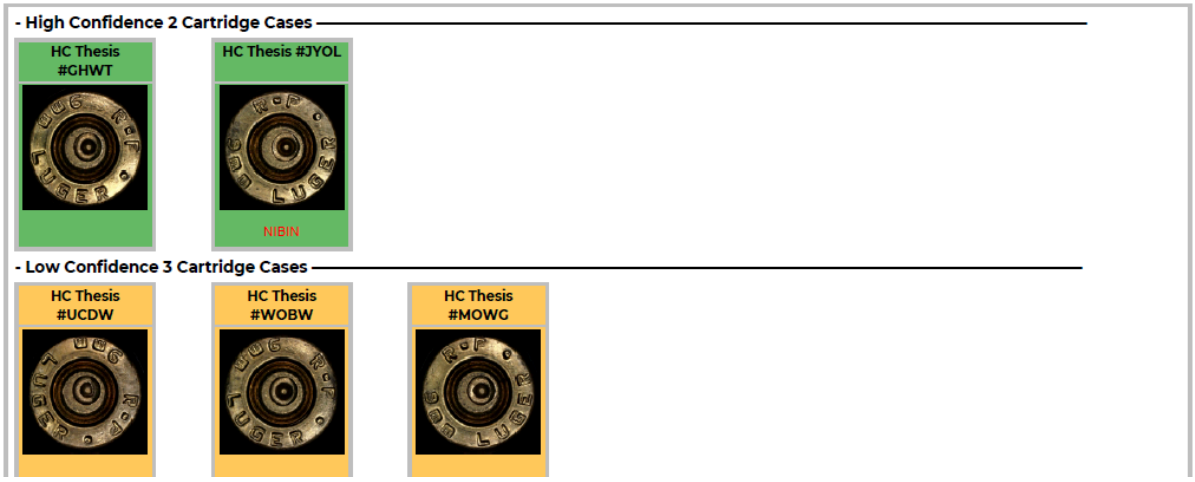


Figure 30: image of five (5) cartridge cases from Remington ammunition that were shot using the Ruger P89 within this study. All cartridge cases originated from the same firearm. Two (2) cartridge cases, GHWT and JYOL at a high confidence and three (3) cartridge cases, UCDW, WOBW, and MOWG at a low confidence.

When examining the CSA Triage report for the Glock 19, the BIQ Triage concluded that all thirty (30) cartridge cases originated from the same firearm at a high confidence. Even when examining the various ammunition brands, the BIQ Triage still concluded that all cartridge cases

originated from the same firearm at a high confidence. When examining the CSA Triage report for the Beretta 92FS, the BIQ Triage concluded that all thirty (30) cartridge cases derived from the same firearms at a high confidence. When analyzing the cartridge cases within the individual ammunition brands, all cartridge cases derived from the same firearm at a high confidence regardless of ammunition brand. For the Taurus PT92, the CSA Triage report stated that all thirty (30) cartridge cases derived from the same firearm at a high confidence. Also when examining the individual ammunition brands within this firearm, the BIQ Triage concluded that all of those cartridge cases derived from the same firearm at a high confidence.

For the CSA Triage report conducted for the SCCY CPX firearm, all thirty (30) cartridge cases emerged from the same firearm. However, when viewing the individual ammunition brands the results were scattered. When analyzing those CSA Triage reports, the cartridge cases from the Winchester, Maxx Tech, Blazer, CCI, and Wolf ammunition all stemmed from the same firearm at a high confidence. The only ammunition brand that had low confidence and undetermined results was Remington. *See Figure 31.*

CRIME SCENE ANALYSIS TRIAGE REPORT

POSSIBLE FIREARMS[1] = 1

This report is intended to provide guidance for entry of fired cartridge cases into NIBIN and as an investigative aid. Investigative leads produced from this Crime Scene Analysis Triage Report should not be used solely to establish probable cause. Microscopic examination by a Forensic Firearm Examiner is required to confirm the associations identified in this report in accordance with agency policy.

EVENT INFORMATION

CASE/INCIDENT#	HC Thesis
DATE/TIME OF INCIDENT	07/22/2024 (CST)
LOCATION OF INCIDENT	UNIVERSITY OF CENTRAL OKLAHOMA 35° 39' 27.0216" N / 97° 28' 15.4168" W

SCAN SUMMARY

CARTRIDGE CASES	CALIBER
5	9mm Luger / 9mm Parabellum / 9mm Luger +P / 9x19mm Parabellum

CARTRIDGE CASES RECOVERED

Firearm #1: 4 Cartridge Cases - Caliber: 9mm Luger / 9mm Parabellum / 9mm Luger +P / 9x19mm Parabellum - Breech Face: Granular - Firing Pin: Circular

- High Confidence 3 Cartridge Cases

- Low Confidence 1 Cartridge Case

Undetermined: 1 Cartridge Case

Figure 31: image of five (5) cartridge cases from Remington ammunition that were shot using the SCCY CPX within this study. Four (4) cartridge cases, GDYL, TTZN, ZYOQ, and SGDN, originated from the same firearm. Three (3) cartridge cases, GDYL, TTZN, and ZYOQ, at a high confidence and one (1), SGDN, at a low confidence. One (1) cartridge case, VOZC, was labeled as undetermined.

When analyzing the Springfield XD9 CSA Triage report, all thirty (30) cartridge cases derived from the same firearm; however, twenty-eight (28) cartridge cases were at a high confidence while the other two (2) were at a low confidence. When analyzing the different ammunition brands, the results were scattered. For instance, the BIQ Triage concluded that the cartridge cases from the Maxx Tech, Blazer, CCI, and Wolf ammunition all originated from the same firearm at a high confidence. However, the results for the cartridge cases under the Winchester and Remington ammunition vary greatly. *See Figures 32-33.* As an example, on the CSA Triage report for Winchester ammunition, three (3) cartridge cases originated from the same firearm at a high confidence; however, the other two (2) cartridge cases originated from a second firearm at a low confidence. *Refer to Figure 32.* When analyzing the CSA Triage report for Remington ammunition, three (3) cartridge cases originated from the same firearm at a low confidence and the other two (2) cartridge cases were labeled as undetermined. *Refer to Figure 33.*

CRIME SCENE ANALYSIS TRIAGE REPORT

POSSIBLE FIREARMS[1] = 2

This report is intended to provide guidance for entry of fired cartridge cases into NIBIN and as an investigative aid. Investigative leads produced from this Crime Scene Analysis Triage Report should not be used solely to establish probable cause. Microscopic examination by a Forensic Firearm Examiner is required to confirm the associations identified in this report in accordance with agency policy.

EVENT INFORMATION

CASE/INCIDENT#	HC Thesis
DATE/TIME OF INCIDENT	07/22/2024 (CST)
LOCATION OF INCIDENT	UNIVERSITY OF CENTRAL OKLAHOMA 35° 39' 27.0216" N / 97° 28' 15.4168" W

SCAN SUMMARY

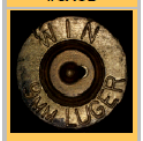
CARTRIDGE CASES	CALIBER
5	9mm Luger / 9mm Parabellum / 9mm Luger +P / 9x19mm Parabellum

CARTRIDGE CASES RECOVERED

Firearm #1: 2 Cartridge Cases - Caliber: 9mm Luger / 9mm Parabellum / 9mm Luger +P / 9x19mm Parabellum - Breech Face: Granular - Firing Pin: Circular

- Low Confidence 2 Cartridge Cases

HC Thesis #GAOB



NIBIN

HC Thesis #PBGN

Firearm #2: 3 Cartridge Cases - Caliber: 9mm Luger / 9mm Parabellum / 9mm Luger +P / 9x19mm Parabellum - Breech Face: Granular - Firing Pin: Circular

- High Confidence 3 Cartridge Cases

HC Thesis #BERN

HC Thesis #MZAZ

HC Thesis #YBNB

NIBIN

Figure 32: image of five (5) cartridge cases from Winchester ammunition that were shot using the Springfield XD9 within this study. Two (2) cartridge cases, GAOB and PBGN originated from one (1) firearm at a low confidence. Three (3) cartridge cases, BERN, MZAZ, and YBNB originated from a second (2nd) firearm at a high confidence.

CRIME SCENE ANALYSIS TRIAGE REPORT

POSSIBLE FIREARMS[1] = 1

This report is intended to provide guidance for entry of fired cartridge cases into NIBIN and as an investigative aid. Investigative leads produced from this Crime Scene Analysis Triage Report should not be used solely to establish probable cause. Microscopic examination by a Forensic Firearm Examiner is required to confirm the associations identified in this report in accordance with agency policy.

EVENT INFORMATION

CASE/INCIDENT#	HC Thesis
DATE/TIME OF INCIDENT	07/22/2024 (CST)
LOCATION OF INCIDENT	UNIVERSITY OF CENTRAL OKLAHOMA 35° 39' 27.0216" N / 97° 28' 15.4168" W

SCAN SUMMARY

CARTRIDGE CASES	CALIBER
5	9mm Luger / 9mm Parabellum / 9mm Luger +P / 9x19mm Parabellum

CARTRIDGE CASES RECOVERED

Firearm #1: 3 Cartridge Cases - Caliber: 9mm Luger / 9mm Parabellum / 9mm Luger +P / 9x19mm Parabellum - Breech Face: Granular - Firing Pin: Circular

- Low Confidence 3 Cartridge Cases

Undetermined: 2 Cartridge Cases

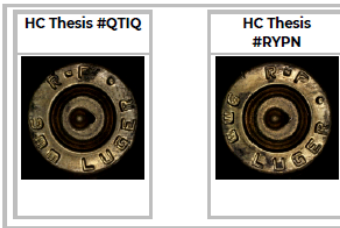


Figure 33: image of five (5) cartridge cases from Remington ammunition that were shot using the Springfield XD9 within this study. Three (3) cartridge cases, ATAC, FWWB, and AGYA all derived from the same firearm at a low confidence. The two (2) other cartridge cases, QTIQ and RYPN were labeled as undetermined.

The last firearm that had its CSA Triage report analyzed was the Smith & Wesson M&P9. When analyzing the CSA Triage report for all thirty (30) cartridge cases, the BIQ Triage concluded that all cartridge cases stemmed from the same firearm at a high confidence. Once analyzing the individual ammunition brands, the BIQ Triage also concluded that regardless of ammunition brand, all cartridge cases originated from the same firearm at a high confidence.

Practical BIQ Significance

Upon reviewing the results, it is evident that the BIQ Triage algorithm fulfills its intended purpose. When focusing on the metadata tests, the BIQ triage algorithm performed well in its focus on the class and individual characteristics of each cartridge case. In regards to the edge check test, the BIQ triage algorithm effectively detected the edge since two hundred and fifty-four (254) out of the three hundred (300) cartridge cases did not need to be adjusted. While the BIQ correctly detects the edge check most of the time, the user should still verify each edge to ensure that no cartridge cases need to be adjusted. Pertaining to the rotation effects test, the BIQ triage algorithm successfully identified that all cartridge cases originated from the same firearm at a high confidence, regardless of the orientation of the parallel marks, drag mark, and ejector mark. This means that orientation of the markings on a cartridge case does not have an influence on the BIQ triage and therefore does not have to be perfect when being scanned. Regarding the recovered vs test-fired metadata test, the BIQ algorithm makes its analysis based on class and individual characteristics rather than the information that is entered into the test-fired category. As for the breech face patterns metadata test, there are specific pattern type combinations that the BIQ triage algorithm will always result in two (2) firearms,

high confidence. These combinations include: Arch to Parallel, Circular to Parallel, Arch to Circular, Arch to Crosshatch, and Crosshatch to Circular. The only recommendation for the metadata effects section concerns the breech face patterns metadata test. Training for those using BIQ should consist of knowing what the different breech face patterns look like in order to ensure that all cartridge cases have the correct breech face pattern type classification.

When focusing on the overall triage performance, the BIQ triage had some difficulties at making comparisons when being asked to compare three hundred (300) cartridge cases at once. For that reason, agencies using BIQ should use a maximum of forty-two (42) cartridge cases to be compared within a CSA triage report. This is recommended because as mentioned on pages 53-54, the BIQ triage algorithm started to incorrectly group cartridge cases when having it compare three hundred (300), ninety (90), sixty (60), seventy-two (72), and forty-four (44) cartridge cases. If more than forty-two (42) cartridge cases are compared at once, then the user should break those cartridge cases into smaller batches along with having a firearms examiner look to ensure that all cartridge cases did derive from that specific number of firearms the CSA triage report concluded. As for the various ammunition brands, since the BIQ triage algorithm had some difficulties with comparing cartridge cases of Remington and Winchester ammunition, the user should avoid using these two (2) brands when possible. However, a reason why the BIQ triage algorithm incorrectly grouped some firearms could be because Remington and Winchester ammunition typically have a smaller primer surface than Maxx Tech and Wolf ammunition, which can be seen on page 27. This means that the

cartridge cases of Remington and Winchester ammunition may have less individual characteristics for the BIQ triage algorithm to focus on. The agency using BIQ should explore how well the BIQ triage algorithm makes its comparisons with other ammunition than the ones used within this study.

Overall, BIQ fulfills its intended purpose as an investigative tool to assist with casework; however, verification of its results should be carried out. One way that the results can be verified is through the virtual correlation center (VCC). VCC involves active firearm examiners remotely reviewing the CSA Triage Report and cartridge cases for some of the errors the algorithm makes.

Limitations

There are several limitations involved in this study. Those limitations include only ten (10) firearms were used, only three hundred (300) cartridge cases were used, only 9mm Luger ammunition was used, and only center fire cartridge cases were used rather than rimfire. For future research, one recommendation is to use more firearms and cartridge cases. By using a larger sample size, this would eliminate potential errors along with providing a more accurate conclusion on the BIQ triage. A second recommendation is to use more than one caliber because 9mm is not the only caliber typically found on scene. For instance, .45 ACP might also be found on scene. The last recommendation is to use both centerfire and rimfire cartridge casings. By utilizing both centerfire and rimfire cartridge cases, this would allow the researcher to evaluate the triage report to its full potential since BIQ works for both centerfire and rimfire.

Conclusion

All in all, the BIQ Triage did what it was intended to do; however, like most instruments within forensic science, there is always room for improvement. Recall, BIQ is an instrument

created by Evidence IQ that has the capability to photograph cartridge cases at various lightings. BIQ is also used as an investigative tool for law enforcement to help speed up their casework by scanning cartridge cases virtually and providing them with a CSA Triage Report which illustrates the number of potential firearms involved at a crime scene. With that, the purpose of this research was to evaluate the BIQ Triage algorithm to its full potential. This study involved ten (10) of the most commonly found firearms at a crime scene along with three hundred (300) cartridge cases, all 9mm Luger caliber and six (6) commonly available ammunition brands. This research started off by conducting several tests of the metadata to determine if the information entered for the orientation, category, or breech face pattern of the cartridge cases had significant impact on its analysis. After all metadata was tested and analyzed, it was discovered that the information put in the metadata did not have an impact on the algorithm's analysis, with the exception of a few breech face patterns.

In regards to the CSA Triage reports, it took the BIQ Triage algorithm approximately an hour and a half (01:30:00) to conduct a CSA Triage report for all three hundred (300) cartridge cases. However, when asking the algorithm to conduct a CSA Triage report for the thirty (30) cartridge cases within each individual firearm, it took approximately one minute and two seconds (00:01:02). When interpreting the results from all three hundred (300) cartridge cases, the BIQ Triage concluded that seven (7) firearms were involved with this study; however, the ground truth was ten (10) firearms. Due to this, the results were analyzed further. Ten (10) additional CSA Triage reports were conducted, each obtaining thirty (30) cartridge cases from each firearm. The results from this illustrate that the BIQ Triage had some difficulties with the Ruger LC9, Ruger P89, SCCY CPX, and Springfield XD9 firearms. A further breakdown was conducted regarding the sixty (60) and ninety (90) cartridge cases that were incorrectly grouped which

revealed that the BIQ Triage started to incorrectly group cartridge cases when it was asked to compare forty-two (42) or more cartridge cases. In addition to this, an analysis was performed involving each ammunition brand from each firearm. This illustrated that the BIQ Triage had difficulties with its analysis for cartridge cases of Remington ammunition. Several match score groups were conducted afterwards to determine the root cause of the problem; however, this encounter ended up being unsuccessful due to the proprietary nature of the scores. RStudio was then used as a way to illustrate the data collected throughout the research.

Continued research for BIQ could result in a better camera resolution. By increasing the camera resolution, this may alter the way the BIQ Triage performs its analysis by ensuring that all individual characteristics are clearly visible. While a firearms examiner may be able to correct the results produced by the BIQ Triage, for those that have little knowledge about firearms, having a better camera resolution would greatly assist them. Another option for continued research could result in a better understanding of the match score groups and its significance to the BIQ Triage.

References

Aguirre, K. (2022, March 17). *Asheville Police Purchase Ballistic System to Cut Down on Gun Crimes*. https://wlos.com/news/local/asheville-police-department-purchase-ballistic-iq-system-gun-crimes-josh-meindl-apd-shootings-shots-fired

Alsdurf, J. W., Law, E. F., & Luehr, S. C. (2024). Performance evaluation of a Cadre Forensics TopMatch-GS 3D system for cartridge case comparisons. *Journal of Forensic Sciences*. https://doi.org/10.1111/1556-4029.15688

Brand, N. W., Berger, C. E. H., Mattijssen, E. J. A. T., Stoel, R. D., & Witteman, C. L. M. (2020). Validity and Reliability of Forensic Firearm Examiners. *Forensic Science International*, 307, 1–12. https://doi.org/10.1016/j.forsciint.2019.110112

Brubaker, M., Duez, P., Lilien, R., & Weller, T. (2015). Introduction and Initial Evaluation of a Novel Three-Dimensional Imaging and Analysis System for Firearm Forensics. *AFTE Journal*, 47(4), 198–208.

Bureau of Alcohol, Tobacco, Firearms and Explosives. (n.d.). *National Integrated Ballistic Information Network (NIBIN)*. https://www.atf.gov/resource-center/docs/undefined/nibin-fact-sheet-june-2020

Carriquiry, A., Hare, E., & Hofmann, H. (2017). Automatic Matching of Bullet Land Impressions. *The Annals of Applied Statistics*, 11(4). https://doi.org/10.1214/17-AOAS1080

CartWin Professional Edition. (2023a). *CartWinPro*. https://www.cartwinpro.com/index_us.html

Centre of Forensic Sciences. (2019, May 21). *Integrated Ballistics Identification System (IBIS)*, 1-2.

https://cfsmigrationdocs.blob.core.windows.net/pdf-english/IBIS%20%20Information%20Sheet%20-%20May%2021%2C%202019.pdf

Davis, J. (2010). Primer cup properties and how they affect identification. *The Journal of the Association of Firearms and Tool Mark Examiners*, *42*(1), 3–22.

Demuth, W. E., & Grom, T. L. (2012). IBIS Correlation Results of Cartridge Cases Collected Over the Course of 500 Firings from a Glock Pistol. *The Journal of the Association of Firearms and Tool Mark Examiners,* 44(4), 361–365.

DiEmma, G., Jones, N., & Shute, R. (2022). 2022 Update: 3D Imaging Technologies and Virtual Comparison Microscopy for Firearms Examination, A Landscape Study. *Forensic Technology Center of Excellence, U.S. Department of Justice, Office of Justice Programs, National Institute of Justice*, 1–21. https://forensiccoe.org/private/6310c16744dbb

Edwards, R. L., & Luehr, S. C. (2021). Ballistics IQ: From a Forensic Firearm and Toolmark Examiner's Perspective. *Evidence IQ*, 1-4.

Evidence IQ. (n.d.). *Ballistics IQ - Evidence IQ*. https://evidenceiq.com/ballistics-iq/

Firearms and Toolmarks. National Integrated Standards and Technology. (2023, May 11). https://www.nist.gov/firearms-and-toolmarks

Firearm Examiner Training. (2008). *Firearm Examiner Training*. https://projects.nfstc.org/firearms/module09/fir_m09_t09_01.htm

Forensic Analytical Crime Lab. (2021*). Firearms & Toolmark Examination*. https://www.facrimelab.com/general-criminalistics/firearms-tool-mark-examination/#:~:text=A%20tool%20mark%20is%20an,within%20the%20questioned%20tool%20mark.

Grassel, J., and Jones, N. S. (Eds.). (2022). 2022 Firearm and Toolmarks Policy and Practice Forum. *RTI Press Publication*, 3-92. https://doi.org/10.3768/rtipress.2022. cp.0014.2204

Hamby, J. E., & Thorpe, J. W. (1997). Firearms Reference Collections - Their Size, Composition, and Use. *Journal of Forensic Sciences*, 42(3), 461–465.

Heard, B. J. (2008). *Handbook of Firearms and Ballistics: Examining and Interpreting Forensic Evidence* (2nd ed.). John Wiley & Son Ltd. https://onlinelibrary-wiley-com.libproxy.uco.edu/doi/epdf/10.1002/9780470694589

Lilien, R. (2020). Evaluation of 3D Virtual Comparison Microscopy for Firearm Forensics within the Crime Lab. *National Criminal Justice Reference Service*, 1–61. https://www.ojp.gov/pdffiles1/nij/grants/255942.pdf

Monson, K. L., Peters, E. M., & Smith, E. D. (2023). Accuracy of Comparison Decisions by Forensic Firearms Examiners. *Journal of Forensic Sciences*, 68(1), 86–100. https://doi.org/10.1111/1556-4029.15152

Monturo, C. (2019). Forensic Firearm Examination. *Academic Press*.

National Institute of Justice. (2023). *Firearm Examiner Training - Comparison Microscope*. https://nij.ojp.gov/nij-hosted-online-training-courses/firearms-examiner-training/module-10/comparison-microscope#:~:text=FBI%20GRC%20File%20Standards&text=The%20GRC%20digital%20database%20file,bullet%20could%20have%20been%20fired.

Nichols, R. G. (2007). Defending the Scientific Foundations of the Firearms and Toolmark Identification Discipline: Responding to Recent Challenges. *Journal of Forensic Sciences*, 52(3), 586–594. https://doi.org/10.1111/j.1556-4029.2007.00422.x

Royal Canadian Mounted Police. (2023). *Firearms Reference Table.* https://rcmp.ca/en/firearms/firearms-reference-table

Silbert, R. W. (1994). DRUGFIRE Forensic Firearms Identification. *Crime Laboratory Digest*, 21(4), 63–68. https://www.ojp.gov/pdffiles1/Digitization/150819NCJRS.pdf

Teitelbaum, J. (2021). *Teitelbaum's Column of Forensic Science - Historical Perspective*, *33*(2), 109–111. https://forensiclibrary.org/wp-content/uploads/2022/06/BureauForensicBallistics_Teitelbaum_ForSciRev_2021.pdf

Thompson, R. M. (1998). Automated Firearms Evidence Comparison Using the Integrated Ballistic Identification System (IBIS). *SPIE Conference on Investigation and Forensic Science Technologies*, 3576, 94–103.

Webb, J. (2013, April 12). *Inside the FBI Reference Firearms Collection*. https://www.fbi.gov/video-repository/newss-inside-the-fbi-reference-firearms-collection/view

Wilson, C. M. (1936). Two New Instruments for the Measurement of "Class" Characteristics of Fired Bullets. *Journal of Criminal Law and Criminology*, 27(1), 97–107. https://doi.org/10.2307/1134861

Zawitz, M. W. (1995, July). Guns Used in Crime. *Bureau of Justice Statistics*, 1-7 https://bjs.ojp.gov/content/pub/pdf/GUIC.PDF