UNIVERSITY OF CENTRAL OKLAHOMA

Edmond, Oklahoma

Jackson College of Graduate Studies

Approaching Objectivity in Firearms Identification:

Utilizing IBIS BULLETTRAX-3D's Sensor Capturing Technology

A THESIS

SUBMITTED TO THE GRADUATE FACULTY

In partial fulfillment of the requirements

For the degree of

MASTER OF SCIENCE IN FORENSIC SCIENCE

By

Deion P. Christophe

Edmond, Oklahoma

2011

Approaching Objectivity in Firearms Identification: Utilizing IBIS BULLETTRAX-3D's Sensor Capturing Technology

A THESIS

APPROVED FOR THE FORENSIC SCIENCE INSTITUTE

APRIL 2011

By________________________________

Name Graduate Advisor

____

Name Committee Member

____

Name Committee Member

APPROACHING OBJECTIVITY IN FIREARMS IDENTIFICATION: UTILIZING IBIS BULLETTRAX-3D'S SENSOR CAPTURING TECHNOLOGY

2011

Deion P. Christophe

Firearm examiners are often asked 1) can a bullet be matched back to the cartridge case from which it was fired? 2) What bullets leave suitable markings for microscopic examinations of this nature? 3) Is there an objective approach for interpreting firearm examiner conclusions derived from microscopic examination? For years, the inability to objectively answer questions of this nature suggests the need for further studies that offer appropriate, reliable conclusions in this discipline. The purpose of this study was to determine the possibility of identifying a bullet back to a cartridge case under both polygonal and conventional firing methods. Additional objectives were to determine which brands of ammunition produced seating marks suitable for comparison purposes, and to determine if a more objective approach for interpreting Firearm examiner identifications exists.

A fixed bin analysis consisting of 53 bins in a side by side representation was utilized to analyze specific regions of interest on a single bullet's bearing surface which was acquired in 1.6mm (band) wide increments by the IBIS BULLETTRAX-3D™ system. Both qualitative and quantitative results provided by this research address concerns that have been outlined by the National Research Council (2009). The major findings in this study indicate it is possible to identify a bullet back to a cartridge case utilizing both conventional and polygonal methods of firing through use of sound methodology. This research also revealed a higher likelihood for abundant sets of striae on ammunition brands containing nickel cartridge cases. It was also established that the IBIS BULLETTRAX-3D™ system can assist examiners with better visualization and the ability to provide more objective conclusions that carry a much higher degree of certainty when conducting bullet comparisons.

ACKNOWLEDGEMENTS

I would like to express great appreciation to my committee chair, Dr. Dwight E. Adams. Your support, guidance, and passion for new direction within my field of expertise have encouraged me to move forward in pursuing new aspects of research through my thesis and other projects.

Next, I would like to thank my committee members, Dr. Mark McCoy and Dr. Wayne Lord. Your assistance and enthusiasm for this research not only influenced me to broaden the intent of my research but also to explore the various directions this research could lead this field of expertise.

Several additional individuals made important contributions to the development and implementation of technology that was used within this research and deserve individual recognition. Dr. Danny Roberge, Dr. Alain Beauchamp, and Firearm and Tool Mark Examiner Paul Murphy of Forensic Technology, thank you for your continued support and direction as I worked with the IBIS BULLETTRAX -3D system, its software, and 3D-Viewer prototype. In addition, thank you for taking time out of your schedule to devote to out-of-the-box research such as this. Your support, time, and knowledge are invaluable and have proven to be beyond the scope of where this technology may lead this field of expertise in the future.

To my family, friends, and co-workers, I would like to say thank you sincerely for all of your incessant support during the last two years as I have worked to accomplish my master’s degree. To each of you, the understanding and unfailing concern for my success has shown through time and time again and I can’t express enough gratitude.

Finally, to my wife, Emily, I wish I had the patience, leadership, and love you have offered me each and every day bottled up so when I reach points of success in my life I could return it to you, the real hero. Thank you for being the best mother to our children and guiding them as I spent countless hours working on this research. I hope you realize none of this would be possible without you in my life.

DEFINITION OF TERMS

(As defined in AFTE GLOSSARY 5th Edition) (Association of Firearm and Toolmark Examiners, 2010)

Alloy - A substance having a metallic property, which is composed of two or more chemical elements, at least one of which is an elemental metal.

Ammunition - The material fired in and from any weapon. One or more loaded cartridges consisting of a primed case, propellant, and with one or more projectiles. Also referred to as fixed or live ammunition.

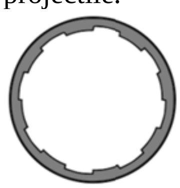
Ammunition Reference - A collection and cataloging of both cartridges and components utilized by the firearms examiner. It is also ammunition used by Test Ranges to calibrate test barrels, ranges and other velocity and pressure measuring equipment. Also known as known standards or ammunition standards**.**

Bullet - A non-spherical projectile for use in a rifled barrel and sometimes contained within a sabot.

Cartridge Case - The container for all needed components which comprise a cartridge.

Chamfer – To bevel a sharp external edge.

Conventional Rifling - Helical grooves in the bore of a firearm barrel to impart rotary motion to a projectile.



Firearms Identification - A discipline of Forensic Science which has as its primary concern to determine if a bullet, cartridge case or other ammunition component was fired by a particular firearm.

Grooves – Helical grooves cut into the bore of a firearm barrel to impart rotary motion to a projectile.

Land – The raised portion between the grooves in a rifled bore.

Polygonal Rifling - Lands and grooves having a rounded profile instead of the traditional rectangular profile.

Projectile - An object propelled by the force of rapidly burning gases or other means.

Toolmark Identification - Toolmark Identification is a discipline of Forensic Science which has as its primary concern to determine if a toolmark was produced by a particular tool.

Seating Lines - The circumferential stria which are parallel to the axis of the projectile, generated on the surface of the bullet by the cartridge case.

Stria - Contour variations, generally microscopic, on the surface of an object caused by a combination of force and motion where the motion is approximately parallel to the plane being marked. These marks can contain class and/or individual characteristics.

LIST OF FIGURES

<u>Figure:</u>

LIST OF FIGURES (Cont.)

LIST OF TABLES

CONTENTS

CHAPTER 1

Introduction

Forensic science is a critically important element in many criminal investigations, as well as the exoneration of individuals who have been wrongly convicted. Recent advances in Forensic science disciplines have provided the potential of linking evidence to perpetrators even in crimes that may have gone unsolved (National Research Council, 2009). Recent recommendations for the field of forensic science, as cited specify three important purposes for advancement in forensic science through research, validation, and reliability studies. These studies will provide:

1. Improvements to assist law enforcement officials in identifying perpetrators with higher reliability,
2. Improvements in Forensic science practices and; thereby, reduce the occurrence of wrongful convictions, and
3. Improvements that will enhance National Security (National Research Council, 2009).

There are challenges that exist in many disciplines of Forensic science. Firearm and Tool Mark analysis is no exception. Enhanced techniques in the analysis and comparison of bullets, and ammunition components are needed in order to create objective standards to establish whether two bullets were fired from the same firearm (Belveal, 1979). No longer can the discipline of Firearm and Tool Mark analysis rely on the subjective nature of an examination based solely upon the experience of the examiner. Conclusions and testimony supporting individualization require this forensic science discipline to adopt procedures that objectively support the link between evidence to a specific source (National Research Council, 2009)

Examiners in the discipline of Firearm and Tool Mark analysis have interpreted its evidence through subjective criteria and based many conclusions on an examiner's experience and training (Hamby, 1973). With the aid of the Association of Firearm and Tool Mark Examiners Theory of Identification (AFTE Theory of Identification), examiners have offered opinions when two surface contours were in "sufficient agreement." The AFTE Theory of Identification states:

> "Sufficient agreement is related to the significant duplication of random tool marks as evidenced by the correspondence of a pattern or combination of patterns of surface contours. Significance is determined by the comparative examination of two or more sets of surface contour patterns comprised of individual peaks, ridges, and furrows. Specifically, the relative height or depth, width, curvature and spatial relationship of the individual peaks, ridges and furrows within one set of surface contours are defined and compared to the corresponding features in the second set of contours. Agreement is significant when it exceeds the best agreement demonstrated between two tool marks known to have been produced by different tools and is consistent with agreement demonstrated by tool marks known to have been produced by the same tool. The statement that "sufficient agreement" exists between two tool marks means that the likelihood another tool could have made the mark is so remote as to be considered a practical impossibility.
>
> The current interpretation of individualization/identification is subjective in nature, founded on scientific principles and based on the examiner's training and experience (Association of Firearm and Toolmark Examiners, 2010)."

While the AFTE Theory of Identification provides examiners with guidelines and criteria for identification, analytically based disciplines such as DNA provide far more objective criteria for declaring a link between sources than disciplines like Firearm and Tool Mark analysis. In both Firearm and Tool Mark analysis, it is important for examiners to distinguish between discernable features on an object. There are three types of characteristics often discussed in Firearm and Tool Mark analysis; they are class characteristics, individual characteristics, and sub-class characteristics. Class characteristics are features shared by many tools of the same type. An example would be two screw drivers identical in appearance. Individual characteristics are random imperfections caused by use, abuse, corrosion, or the manufacturing process. These individual characteristics are often seen and viewed microscopically and are not always apparent with the unaided eye. An example of individual characteristics would be the random imperfections created on the blades of screw drivers. While these imperfections look similar and the overall class is similar, their manufacturing processes may differ so that each blade has microscopic imperfections that will change due to use, abuse, or corrosion. In between class and individual characteristics are sub-class characteristics. Sub-Class characteristics are those imperfections that are part of the overall class or tool type, but are limited to a smaller group source. For instance, gouges in the blade of the screw driver caused by a worn cutting tool used during manufacturing. While this may appear to be unique to that tool, once examined by a series of similar tools it may be determined that this imperfection is only apparent on several tools within the overall class.

Both firearm components and tools are analyzed based on class, subclass and individual characteristics. The task of the examiner is to identify the individual characteristics and assess the agreement between the two tools or components. Knowing the extent of agreement in marks made by different tools and the extent of variation in tools of that particular type is challenging and often involves subjective judgments (National Research Council, 2009). These experienced-based judgments have a tendency to offer bias and lack verifiable data. While the AFTE standards acknowledge that conclusions drawn are subjective assessments, it is well understood that an examiner’s training and experience may ultimately influence conclusions. Currently, there is no consensus regarding the number of individual characteristics needed to make a positive identification in impression evidence disciplines like Firearm and Tool Mark analysis. While class characteristics may be identified, there has yet to be few if any scientific studies that objectively produce the reliable and repeatable methods for the discipline of Firearm and Tool Mark analysis (National Research Council, 2009).

The discipline of Firearm and Tool Mark analysis has had an ample amount of time to establish objective standards in the interpretation of bullet comparisons. On one hand, multiple studies have been published that represent a comprehensive explanation for the basis of this discipline. On the other hand, many publications only describe observations made in the field and lack objective data that support its findings. Albert Hall was one of the first to inform the public that the greatest interest in death investigation was that of the bullet and the pistol. His investigation into the measurements of bullets both pristine and fragmented revealed detailed markings that were of high importance. This may have been the first attempt at establishing objective criteria for examination purposes as these markings represented manufacturing marks from within the rifling of weapons (Hall, 1931). Hall believed that a careful inspection of a firearm would reveal similar markings seen on the bullet fired within it. Hall discovered, in numerous instances, markings that linked both the bullet and the firearm together which laid the foundation for others (Hall, 1931).

Throughout the history of firearm identification others, like Hall, have continued to obtain information leading to the early development of criteria linking a bullet to a firearm. Berg (1979) recognized Victor Balthazard as one of the first to publish a series of papers on methodologies related to the identification of bullets and cartridge cases to individual firearms in the early 1900's. Balthazard's methods consisted of taking a series of photographs around the circumference of test and evidence bullets, enlarging them, and comparing the photos by laying the test prints over evidence prints (Berg, 1979). Rathman (1975) recognized Calvin Goddard and associates for developing the comparison microscope, which advanced the ability for examiners to view marks on ammunition components. It was the first time in firearm examinations that microscopy was utilized to examine bullets and cartridge cases in an attempt to offer a scientific opinion in relation to their similarities or differences. (Rathman, 1975). Many examiners, to include Goddard, throughout the existence of this discipline continued to establish that the conclusions and opinions into the science, investigation and examination of firearm and tool mark components have continuously been relied upon and considered valuable in many criminal cases since the early part of 1925. However, criticism in the field continues and still lacks an objective approach to calculate the percentage of matching striae amongst different firearms or ammunition components (Nichols, 1997). In the 1959 study by Biasotti described by Nichols (1997), he states that Biasotti utilized empirical methods and research which brought forth the idea of consecutiveness and the possibility of preventing misidentifications. By 1969, firearm examiners had established their own professional organization called the Association of Firearm and Tool Mark Examiners (AFTE), dedicated to firearms identification, skills, techniques, and an exchange of information (Berg, 1979). Though diverse contributions have assisted examiners in their ability to examine, analyze, and interpret evidence, in 1997 concerns still existed related to identifications achieved by subjective methods (Nichols, 1997). While experts continued to rely on these early discoveries in the analysis of firearm and ammunition components, the most challenging aspect within the field continues to be the lack of objective, valid, and reliable identification criteria developed through research.

Background

As described within the AFTE Theory of Identification, the subjective nature of opinions or conclusions drawn from examination are commensurate with the firearm examiner's training and experience. Although studies have shown that tools and ammunition components change over time as they come into contact with harder surfaces, limited information about variability between individual tools, guns, and ammunition components are available. Legal challenges have been brought forth on the basis that Firearm and Tool Mark opinions rely on subjective findings by examiners rather than verifiable, objective facts (National Research Council, 2009). The National Research Council (2009) also believes that interpretations within this field are only viewed through the eyes of the examiner and are considered largely to be observations of the mind (Thornton, 1979). However, there are certain aspects of firearm analysis that are objective in nature. For instance, measurements such as the width of lands and grooves, cartridge case diameter, and a bullet's diameter are all objective measurements. When coupled with the examiners ability to ascertain how these characteristics fit together and display similarity or differences between surfaces, powerful conclusions are drawn and typically supported by photographic images. Yet these conclusions and images are now facing serious legal challenges in U.S. courts.

Goddard (1987) recognizes examiner C. E. Waite as having an ambition to see visual evidence offered in support of an examiner's expert opinion. Today visual evidence provides an understanding and offers meaning to an examiners technical testimony. Murdock (1981) states many people ask why it is possible for examiners to offer such definitive opinions in relation to observable features. The answer is simple in the eye of an examiner and relates to the concept of individuality. However, the lack of understanding relates to a deficiency in awareness that most literature associated with individuality was conducted at a time when the rifling of gun barrels was accomplished by removing metal with scrapers and cutters. The technology of this time was an advantageous factor in that these marks or characteristics which could only be viewed on a microscopic level and capturing this detail was a empirical way of describing it. One would imply that this was another attempt at utilizing an appropriate objective method through visual aids to support subjective concepts in research or casework. While prominent examiners like Goddard, Waite, and others are all credited for vast amounts of research into the advancement of the field of Firearm and Tool Mark analysis, a large portion of the analysis and interpretation remains to be subjective observations.

It should be clearly acknowledged that the failure for firearm examiners to develop objective standards is not attributed to professional lassitude. The problem is that objective criteria that exist are so minimal as to seem non-existent (Thornton, 1979). The concepts of individuality and individualization within the discipline of firearm and tool mark analysis are backed by empirical tool mark literature provided by Cassidy (1982) in a timeline from1930 through 1978. The destructive properties associated with every tool change based upon the surfaces they come into contact with. Just as a hammer alters wood or a nail, a firearm alters a bullet. These empirical models exemplify that tools are susceptible to wear and damage when they are extensively used and thus contribute to the likelihood of uniqueness as described by examiners today. However, the link to connect subjective observations with objective methodologies has yet to be established.

Statement of the Problem

Firearm examiners are often asked, “can a bullet be matched back to the cartridge case from which it was fired?” For years, the inability to objectively answer questions of this nature suggests the need for further studies that offer appropriate, reliable conclusions in this discipline. In order to properly answer this question, examiners must think beyond the scope of traditional methodologies. The time has come where the gap between technology and subjectivity must merge and provide improvements that assist law enforcement, improvements that derive more stringent Forensic science practices, and provide improvements that will enhance National security.

Cartridge cases are tubular metallic containers designed to hold various ammunition components (i.e., primer, bullet, propellant powder). During the manufacturing of cartridge cases there is a variance in tensile strength and elasticity that may occur in the annealing phase based on the composition of the raw material used to construct the cartridge case. To firearm examiners, this is important because one brand or lot of ammunition may be made from harder metals such as steel, and this could affect the impressions it will make on bullets or surfaces that it may come in contact with (Lambert, 1971). Most modern day cartridge cases in North America are composed of a 75:25 mixture of copper/zinc alloy (Heard, 2008); while others are nickel, steel, brass, or aluminum. Some casings are soft metals, (i.e., aluminum, brass) but most cartridge cases are often harder than the composition used to jacket the projectiles which they are seated in. However, regardless of the composition, most cartridges start as a sheet of metal. The metal is punched into small disks which are formed into shallow cups and heated to a high temperature and cooled. This process, called annealing, prepares the metal so that it may be formed to various specifications. The cup is then forced through a series of dies and drawn out approximately two to three times to reduce the diameter and lengthen the case body (Prieto, 1982). At Remington Arms, a cartridge case is head stamped with a bunter which applies the manufacturer information (i.e., R-P), the caliber designation, (i.e., .45 Auto, .32 Auto, etc.) and forms the primer pocket. The cartridge cases go through a head turn process which forms the extractor groove and the body of the cartridge case is then annealed in order to prepare the cartridge case for taper and trim processes (White, 2005). During the trim process the cartridge cases are trimmed to size and chamfered. The trimming phase will create burrs on the inside and outside of the cartridge case mouth. The chamfering phase is designed to polish off these burrs both on the inside and outside of the cartridge case mouth. While the tools used to create these cartridge cases are utilized in the production of thousands of rounds, each cartridge case will have its own individuality due to the wear associated with the tool(s) being used over and over again. It is here that the microscopic imperfections become part of an ammunition components unique identity.

Modern bullets can be manufactured through casting, swaging, electroplating, and milling. In this process, bullets are typically made of a combination of metals to include copper, brass, steel, bronze, aluminum and lead, or a single alloy on its own. Most combined metal bullets are called jacketed bullets and the materials used to make them assist in the bullet's overall performance in flight and distance. Most manufacturers strive to find a balance in bullet manufacturing that pertains to both penetration and bullet expansion. For many shooters, the bullet of choice is based on the intended target.

At Remington Arms, projectile manufacturing for pistol ammunition may have a three to four station production process. While some projectiles go through extensive procedures, each projectile or bullet begins as one large "pig". This "pig" is approximately 80 pounds of lead or a lead- free mixture. Each "pig" is melted down in a large smelting pot and turned into a "billet". "Billets" are 225 pound columns that are extruded through a die and compressed into specific diameter lead wire. This wire is guided and coiled into barrels until it will be used. Each of these coils are sent into a tumbler where they are coated with graphite and at this point the lead wire is at its appropriate diameter or caliber and ready to be cut, formed, seated, and or coated. Each coil of lead wire is cut and formed into a projectile while seated into a jacketing material (i.e. copper alloy) which allows the lead core a protective coating and durable exterior surface. Just as described in the manufacturing process of cartridge cases, projectiles are also coated with a harder material as well. This material may be steel, copper or brass alloys, all of which add a durable surface coating to the lead core and assists the bullet in terms of flight and performance (White, 2005).

As a projectile is seated in its respective cartridge case, marks are impressed onto the bearing surface at the base of the projectile in a linear fashion. It has yet to be determined if these marks are individual and unique to each cartridge case and if they are a direct impression due to the trimming, chamfering, or crimping that is described during the manufacturing process. The ability for an examiner to observe these marks is highly likely by utilizing an inertia bullet puller to separate the bullet and cartridge case. However, once a live round has been fired there are limitations during comparison that make for complex identifications difficult due to the over-marking as the bullet is fired through a rifled barrel.

Purpose of the Research

Previous research has explored several methods for reproducing test specimens for comparison purposes when attempting to link a bullet to its respective cartridge case; however, few have explored various brands of ammunition to determine which brands are more likely to produce characteristics worthy of examination. Many methods utilized have fallen short of being objective approaches that can answer questions of this nature. While enhanced techniques in the analysis and comparison of bullets and ammunition components currently exist, few technological approaches have been studied to assist examiners in the field. It was the purpose of this research to utilize the IBIS BULLETTRAX-3D system to objectively assist in the identification of marks on a bullets surface.

Research Questions

Three questions will be addressed in the present study. 1) Is it possible to identify a bullet back to a cartridge case utilizing both conventional and polygonal methods of firing? 2) What brands of ammunition present quality seating marks useful for examination purposes? 3) Is there an approach that can provide examiners with an objective basis in addition to the subjective conclusions derived through microscopic examination?

CHAPTER 2

Review of the Literature

In the field of Firearm and Tool Mark analysis the methodology revolves around the theory of identification as it pertains to the individuality of tool marks. Despite the many strides made in recent years that advance the scientific methodology behind this forensic science discipline, a thorough review of previous literature is necessary to provide a framework for this research.

The theory of identification as it pertains to tool marks enables opinions of common origin to be made when the unique surface contours of two tool marks are in “sufficient agreement”. Several studies have described this “sufficient agreement” by the comparative examination and analysis of tools and components. In 1981, Welch studied the individuality of bullets and cartridge cases. He envisioned that the inside of a cartridge case would leave striations on an exiting bullet that may be identified back to the cartridge case. In his study, Welch examined three types of bullets: plain lead .38 Special (caliber), Full Metal Jacketed (FMJ) 9mm (caliber), and knurled cannelure .38 Special (caliber). The cartridge cases were examined by three methods of removal as well: pulled by an inertia bullet puller, fired in a RG-38 revolver with no barrel, and fired in the same revolver with a barrel. The results indicated that the knurled cannelure bullet produced the best cartridge case marks for identification purposes and all bullets pulled by the inertia bullet puller were considered to be generally suitable for identification purposes.

Levine and Kuehner (1998) observed impressions, mostly in Winchester ammunition, from cartridge case mouths left on respective bullets. In their investigation of these markings (impressions) they found it suitable to compare the impression left on the bullet to a Mikrosil™ cast of the cartridge case mouth area. It was noted by these authors that the impressions were evident even after the passage of the bullet down the barrel. Their research identified that impressions were present in instances where the barrel had polygonal rifling or conventional rifling. However, this research was only conducted with

Winchester brand ammunition and it is unknown if these markings are produced on any other brands of ammunition.

Cassidy (1981) attempted to determine if a bullet could be identified to a .38 Special cartridge case after being recovered from a homicide victim. He utilized a combination of clay, wax, and melted Crayola™ to create a casting material for the inside of the cartridge case. This procedure produced a striated wax replica from the interior surface of the cartridge case. Cassidy was unable to link the striations on the bullet back to the cartridge case that had been recovered at the homicide scene; however, he was able to inter-compare and identify striations on two castings utilizing this technique. Cassidy was the first to attempt the replication and comparison of markings from the inside of a cartridge case

Locke (2005) attempted to replicate the previous work of Levine and Kuehner (1998) by using Winchester and Remington bullets. He noted that several of the bullets appeared to have deep crimp marks and this alone could assist in bullet orientation. Locke reported that Winchester bullets all contained sufficient detail suitable for comparison purposes. Remington bullets lacked sufficient detail for comparison. Locke additionally examined nine Winchester rounds including five 9mm Luger caliber and four .45 caliber which were all fired in Glock pistols with polygonal rifling. The impression marks left on all nine bullets were identified back to their respective cartridge cases using the crimp mark impressions. Locke’s study supported the findings of Levine and Kuehner in that Winchester brand cartridges frequently leave crimp marks on the bullet. He noted that the source of the marks seemed to be a combination of trimming on a rotary face mill, washing, and crimping. In addition, his study indicated that the impression may be dependent upon the composition of the bullet jacket in comparison to the pressure applied to the crimp. Nevertheless, Winchester brand bullets were found to have sufficient cartridge case mouth impressions that could be positively identified back to their respective cartridge cases.

Bennet (2007) describes a case having two bullets fired in polygonal rifled gun barrels. The bullets contained a series of well defined striations that ran from the cartridge case crimp mark parallel to the base of the bullet. He identified the striations as seating marks caused by the cartridge case from which the bullet was loaded. The cartridge cases were comprised of Winchester brass and Winchester nickel. The striations on the land and groove surfaces of the questioned bullets were unidentifiable due to the rifling. However, when the striations on the questioned evidence were compared to those made on test bullets produced by the Winchester nickel cartridge case, sufficient agreement was found and concluded that the evidence bullet was once loaded into the Winchester nickel cartridge case. Bennet states that most examiners answer the question, *"Can a bullet be matched to a cartridge case?"* with a "No." for a number of reasons. This example demonstrated that the relative hardness of the cartridge case in question was critical to producing positive results and did not obliterate the marks on the bullet produced by the burrs within the cartridge case mouth. Bennet stated that copper jacketed bullets loaded in brass revealed minimal markings as compared to copper jacketed bullets loaded in nickel plated cases. While Bennet identified relative hardness as a critical factor in the examination and analysis linking a bullet to a cartridge case, additional research into the investigation of relative hardness of common cartridge case and bullet compositions needs to be investigated. For instance, it can be assumed based on the basic nature of compositions that the order of hardness from most aggressive to least aggressive would be steel, copper, nickel, and then brass. However, a true explanation as to the average hardness ratings for Copper, Nickel, Brass, and Steel has yet to be conducted or explained.

Clow (2008) developed a method for the production of test specimens for the comparison of bullet seating marks. Clow stated the comparison of a bullet back to a cartridge case is relatively rare due to the many variables associated with the limited potential for these marks to exist after firing. For example, these marks have a tendency to be over marked and may cease to exist as a bullet passes down the bore of a barrel. Yet there have been reports by Bennet (2007) and Locke (2005) where these marks arise in case work and are available for comparison. Clow simplified the steps associated with producing test samples. In doing so he reported that an examiner only needs bullets for reloading, a small hammer, a leather or rubber pad, and an inertia bullet puller. He determined that the best results are found when the examiner begins by indexing the cartridge case followed by placing the reloading bullet in the fired cartridge case in nose down orientation. The bullet is tapped with the hammer so that the bullet will selfcenter and become flush with the mouth. By indexing the seated bullet before pulling with the inertia bullet puller, less time will be spent during the comparison phase when comparing the original bullet removed from the cartridge case to the seated bullet.

Literature related to the comparison of bullet seating marks and the feasibility of matching a bullet to a cartridge case has been demonstrated. Welch (1981), Levine et. al (1998), Bennett (2007), Cassidy (1981), Locke (2005) and Clow's (2008) have not examined diverse brands of ammunition or explored the factors associated with conventional or polygonal rifling on fired bullets.

Previous research identified surface hardness as a key factor in whether a bullet may be linked back to a cartridge case. This study will utilize previous methods as proposed by Clow (2008) to reproduce seating marks on bullets both fired and pulled from cartridge cases. It is predicted that harder cartridge case metals will produce more prominent seating marks on bullets of softer compositions that are suitable for IBIS BULLETTRAX-3D acquisition. In addition, it is predicted that utilizing this technological tool may provide a more objective means for clarifying the degree of correspondence viewed in the comparison of the seating marks on both fired and pulled bullets from the same cartridge case.

CHAPTER 3

Research Methodology

This research attempted to answer three research questions. The first question is whether or not it is possible to identify a bullet to a cartridge case from which it was fired. Research by Bennet (2007), Clow (2008), Welch (1981), and Levine and Kuehner (1998) all identified the possibility for seating marks to be observed on the base of a bullet utilizing various methods for test specimen. While these author's indicate relevant methodologies none of these methods have been rigorously tested or validated over a series of ammunition types. Winchester ammunition is one brand that is consistent throughout many of these authors' studies; however the practical nature of matching a bullet back to a cartridge case after firing has yet to be thoroughly examined. In order to determine if it is possible to identify a bullet back to a cartridge case the researcher will utilize Clow's (2008) methodology for the production of test specimens for the comparison of bullet seating marks.

Conventional and Polygonal methods of rifling will be utilized in this study. Polygonal rifling is one of the oldest forms of rifling created by German engineers prior to the Second World War (Doyle, 2010). The term polygonal means multiple sides and angles and these barrels are noted to be some of the most durable and accurate barrels on the market due to the limited amount of deformation created from the grooves within the barrel of the firearm. In terms of modern day firearm manufacturing methods polygonal rifling is one of the newest mechanical forms of rifling seen in the firearms industry today and contains an octagonal or hexagonal profile of hills and valleys within the bore of a firearm (Doyle, 2010). This type of rifling is completed by a steel mandrel being forced down the barrel and hammered until the barrel takes the shape of the desired rifling unlike traditional conventional rifling.

Conventional rifling on the other hand is etched or cut. Where each cut represents a groove within the barrel and the ridge between each groove represents as land (Cantrell, 2010). Together these surfaces define the type of rifling within the barrel of the firearm. Most conventional rifled barrels are formed utilizing cutters that remove metal, whereas polygonal rifling metal is displaced by the force of a hammer pounding on the exterior surface.

The second question is what brands of ammunition present quality seating marks useful for examination purposes? The literature has shown that there is a limited amount of research that examines the breadth of variability associated with tools and guns (National Research Council, 2009). The same information can be interpreted in relation to ammunition brands and composition types. It has yet to be determined whether or not the surface hardness associated with specific cartridge case and bullet jacket compositions determine the likelihood that seating marks will be observed on the base of a bullet. In order to examine this question the researcher will call on Bennet's (2008) research and evaluate the surface hardness of the compositions utilized in this study.

The third problem that this research will examine is an approach that can provide examiners with an objective basis in addition to subjective conclusions derived through microscopic examination. This question will be examined by means of microscopic comparisons through use of the IBIS BULLETTRAX-3D™ system. This system is designed to capture specific regions of interest on a bullet's bearing surface in 1.6mm (band) wide increments. While the purpose of the system is to capture this information digitally, it also processes this digital information through a sequence of operations which in return produces both a 3D topographical band (carpet) and a 3D model for 3D virtual comparison. The 3D virtual comparison is accomplished through a software prototype that enables users to manage the 3D information that is acquired by the IBIS BULLETTRAX-3D™ system. It should be understood that the IBIS BULLETTRAX-3D™ system is no more than a technological tool that assists users with the ability to link investigative information across jurisdictional boundaries. The advancement of this technological tool was recently enhanced and provides examiners with a more objective approach for the basis of conclusions.

This objective approach is best described by the system's ability to record any and all surface variations that would normally be viewed under microscopic examination. As these variations are captured and processed through this system, variations can be viewed in comparison with other known or unknown samples. Typically subjective opinions are drawn during the examination and comparison phase. This system offers an examiner the ability to examine key features that may be more clearly considered topographical individualities, which through more advancement in technology may be a topographical GPS for bullets and their markings.

A fixed bin method will be utilized to analyze 3D topographical information that is acquired by the IBIS BULLETTRAX-3D™ system. Budowle et. al. (1991) utilized a similar approach for the statistical analysis and evaluation of allelic data for DNA analysis and determined the binning approach to be a conservative statistical approach to compensate for sampling error, differences among racial groups, population and specific technology. In their approach fixed bin analysis assisted in the ability to avoid undue weight being placed on an accused individual because each sample assessed was assessed as a frequency of occurrence based on the population. Furthermore, this approach identifies that bias will not be placed on an individual selected at random in the population when such methodology is utilized.

In this research, each 3D topographical band acquired by this system is designed to capture specific regions of interest on a single bullet's bearing surface in 1.6mm (band) wide increments (viewed as a carpet) and will be enlarged for analysis to be ~279mm in height by ~ 5.5mm wide. A fixed bin method consisting of a total of 53 bins in a side by side representation will then be utilized in the analysis phase of this research. These 53 fixed bins will be overlaid atop two 3D topographical bands being compared for matching striations. Each individual bin's dimensions with no overlap on both the 9mm bullets and 40 caliber bullets analyzed in this research will be 9.5mm in height by 25.4 mm wide using the enlarged carpets. A side by side bin that has at least one matching striation in alignment when the two carpets are compared in best fit positions will be acknowledged as a positive result. For this research (*x*) represents the number of positive results out of 53 side by side bins.

The number of positive results' (*x*) in the 53 side by side bins follows a binomial probability distribution given by

$$P(X = x) = \binom{53}{x} p^x (1-p)^{53-x}$$

To estimate the probability of a positive result (*p*) in any random pair of side by side bins, twelve polygonal and conventional fired 3D bullet topographical bands (carpets) in 9mm caliber were provided by Forensic Technology Incorporated. All possible pairs (66 each of the polygonal and conventional fired bullets) were examined to determine the best possible fit, and the number of positive results' for each pair of bands was tabulated. An estimate of *p* for each pair of bands was calculated by dividing the number of positive results' by 53. These estimates of *p*, for both the polygonal and conventional fired bullets, were then averaged and a 95% upper confidence limit was calculated using SAS version 9.1. This upper confidence limit was used as a conservative estimate of *p* in the binomial formula to calculate the probability (and likelihood) of counting at least as many positive results' as were counted in the known matching pairs.

Photographic illustrations of 3D representations will accompany the results of all bullets that were captured with this technology (see *Figures 1& 2)*.

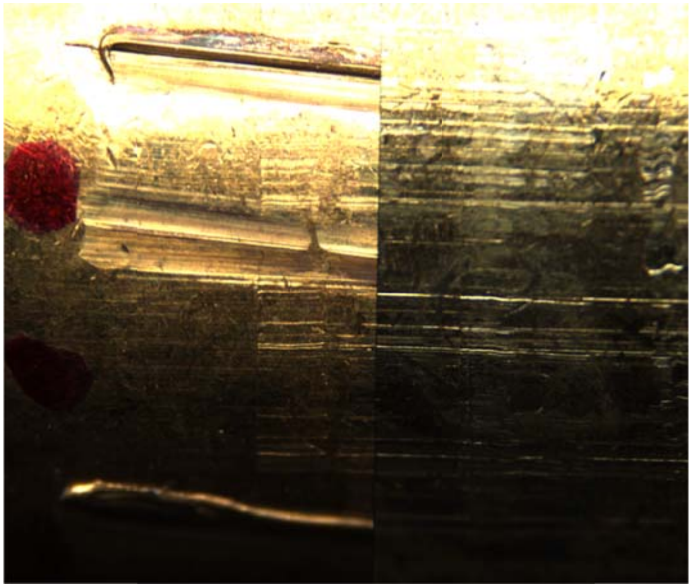


Figure 1. Sample 2D photograph taken on the comparison microscope of the one conventional fired round of ammunition with seating marks compared and identified with one reloaded and pulled projectile of same caliber.

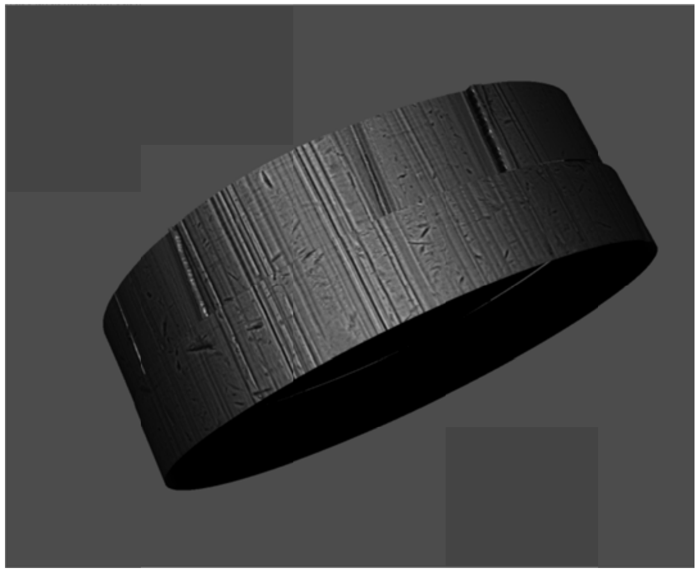


Figure 2. Sample 3D photograph acquired by the IBIS BULLETTRAX-3D sensor of the one conventional fired round of ammunition with seating marks compared and identified with one reloaded and pulled projectile of same caliber.

Procedure for Collecting Data

Two firearms were chosen for this study. The first firearm selected is the Glock© model 27, .40 caliber semiautomatic pistol with a 3.5 inch barrel. While Glock© pistols are common in casework and carried by law enforcement personnel, these firearms render some of the most difficult bullet comparisons based on their interior rifling configuration. The Glock© pistol is one of several pistols on the market that contain polygonal rifling (Police Equipment Reviews, 2010) (see *Figure 3*).

Figure 3. .40 caliber Glock© model 27 utilized in this research.

The second firearm chosen for this study was the Beretta© model 96, .40 caliber semiautomatic pistol with a 5.0 inch barrel (see *Figure 4)*. This particular firearm has traditional cut rifling created by either a broaching rod or a button plug forced down the barrel to create sharp edges with defined corners in a spiral pattern of left or right orientation (Doyle, 2010).

Figure 4. .40 caliber Beretta© model 96 utilized in this research.

Four brands of ammunition were chosen for this study in order to include diverse combinations of cartridge case and projectile jacket metal compositions. In relation to Bennet's (2007) surface hardness study, the following compositions were examined in order to determine the likelihood that bullet seating marks will be observed on the base of fired projectiles.

- 40 Remington Golden Saber™ 40 S&W caliber 180 grain Jacketed Hollow Point (JHP) with a brass jacketed projectile and a nickel cartridge case.
- 40 Hornady TAP® 40 S&W caliber 180 grain Jacketed Hollow Point (JHP) with copper jacketed projectile and a nickel cartridge case.
- 40 Wolf® brand 40 S&W caliber 180 grain Full Metal Jacket (FMJ) (Bi-Metal) with copper jacketed projectile and steel cartridge case

- 40 Federal® brand 40 S&W caliber 165 grain Full Metal Jacket with copper jacketed projectile and brass cartridge case.

Each round of ammunition was marked with an item number and indexed with a permanent marker from the projectile onto the cartridge case before firing. For those brands of ammunition with Jacketed Hollow Points, a small screw was drilled into the Hollow Point cavity to prevent expansion for testing purposes. Twenty (20) rounds of each brand of ammunition were fired in each pistol into the ballistics water tank one round at a time, and the projectile and cartridge case was then collected. Each fired cartridge case was then resized in a RCBS Rock Chucker 2 Single Stage Press with a .40 S&W resizing die (see *Figure 5)*.

Figure 5.

By resizing each fired cartridge case the cartridge case would resume its original shape and it was proposed that the cartridge case mouth would be more likely to mark newly seated reloading bullets. Reloading bullets of the same caliber and grain size were then inserted into the resized fired cartridge case in a nose down fashion (to increase markings on bearing surface). This process was completed utilizing the same RCBS reloading press and a .40 S&W bullet seating die. Once the original fired cartridge case had been reloaded with a newly seated reloading bullet, it was then pulled with an inertia bullet puller. The final procedure was to determine if the seating marks on both the original fired projectile and the reseated inertia pulled projectile were identifiable to the same cartridge case. The comparison microscopy analysis was completed on a LEEDS Comparison Microscope (see *Figure 6)*.

Figure 6.

The LEEDs comparison microscope is designed and built with Olympus optics. These optics provide the examiner with an optical system that has the highest correction level available on the market. The optics on this system eliminates optical irregularity and provides high-resolution images. The LCF 1600 optical system is designed using two Olympus macro zoom bodies with built-in aperture diaphragms. These are matched for magnification positions that stay in focus throughout the zoom ratio.

The LCF 1600 has a total visual magnification range of 6x – 102x and a zoom ratio of 16:1 with the use of a 1x plan corrective objective. The LCF 1600 has 14 commonly used matched magnification positions. The extended magnification range on the microscope allows the examiner to observe evidence without any adjustment to focus, instrument height or ergonomics. All visual magnifications are marked on the zoom knobs, eliminating the need for the use of multipliers to determine the viewed magnification. A National Institute of Standards and Technology (NIST) traceable certificate of magnification matching has been provided with this system at the time of installation (Leeds Forensic Systems, 2010).

Procedure for Assessing Data

Acquisitions of fired and pulled bullet specimens were obtained utilizing the IBIS BulletTrax-3D™ system. Each known pair group was then compared utilizing the software prototype to enable the user to view and manage the 3D information that has been acquired by the IBIS BULLETTRAX-3D™

system. The 3D viewer allowed the user to manually enhance the amount of information that can be viewed within the acquired region of interest or 1.6mm band.

Enhancement within the 3D viewer allows the user to view the 1.6mm band in a mosaic (black and white impression) image and digitally enhances its features. The 3D viewer has many options that allow the user to better visualize both gross and minute detail. One of the most diverse enhancement features is known as the Alpha Factor menu. The Alpha Factor menu allows users to enhance minute detail on a scale from 1.0 to 10.0. Each time the Alpha Factor scale is increased, it will reveal more 3D microscopic features on the bullet without changing its shape. For instance, an Alpha Factor level 1.0 may show a 3D view of impressed areas on the bullets surface but only at a minute height, while an Alpha Factor level 8.0 will show a more enhanced view of those features at a much greater height further enhancing the bullets topography and microscopic features. Each Alpha Factor level enhances the 2D views around the circumference of the bullet at the same level of escalation.

In addition to the Alpha Factor menu, the 3D viewer can acquire an enhanced image with texture. In IBIS BULLET TRAX-3D's sensor capturing technology, only the topography within the depth of field reflects light back to the camera. Since examiners are working with an object that is circular in nature, and the comparison microscope only allows the user to see what is in the examiners field of view, the sensor on the other hand, takes a picture of the bullets surface area and field of view capturing all detail. As the sensor on the IBIS BULLETTRAX-3D™ camera moves along the region of interest, it will accumulate all the 2D images and take the best overall image in order to create the best in focus 2D image. To convert this 2D information into 3D topography, the captured sensor images that correspond with the brightest values are then converted to represent overall texture (i.e. peaks and valleys) on the bullets surface. In the viewer, the three texture settings are best described as 3D renderings of: the raw data image, the best in focus 2D image, and the 3D topography image. Since examiners are typically viewing a circular image under variations of light and the human eye has to adjust for the peaks and valleys in terms of brightness and darkness, these three settings allow the user to visualize the same features by enhancing the raw data and compiling the information to create a better visual representation of overall bullets topography. The unique aspect of this technology is that there is an unlimited depth of field associated with this viewer and the user is able to manually rotate the image in any direction imaginable. This ultimately allows a better ability for the examiner to examine the entire bullets topography while utilizing this technology to identify unique surface contours that can then be re-examined under microscopic examination. Another great advantage is the ability to examine several bullets at once.

This research utilized subjective and objective approaches in the analysis of the seating marks on both the original fired projectile and the reseated pulled projectile. Fired bullets were examined in comparison with the reloaded bullets to determine if there were similarities in striations where sufficient correspondence is viewed on each bullet. Should there be sufficient correspondence; the bullets were then oriented, photographed, and maintained for the IBIS BULLETTRAX-3D™ acquisition.

In the analysis phase of this research, the sensor capturing technology of Forensic Technology WAI Incorportated was utilized to capture surface topography on each known matching pair of bullets. Each bullet within a pair was examined microscopically on the LEEDs comparison microscope (i.e. pulled and fired), and significant areas of striated marks were then oriented in order to capture areas with sufficient detail with the IBIS BULLETTRAX-3D™ sensor. A cross comparison was then carried out utilizing the IBIS 3D Viewer prototype.

This technological approach may later be used to quantify topographical similarities for 2 dimensional and 3 dimensional bullet striations, or what this researcher will call regions known to have sufficient similarities of correspondence. In addition, because Forensic Technology WAI Incorporated has utilized precise processing methods to reproduce 2D and 3D features captured through acquisition utilizing their IBIS BULLETTRAX-3D™ sensor, the virtual comparison, as seen in the IBIS BULLETTRAX-3D™ viewer prototype may provide high repeatability and reproducibility that can serve as a Geographic Positioning System (GPS) when viewing individual characteristics on bullets topography. Since these GPS locations can currently be viewed as 3D topography, future improvements in this technology may interpret or convert this topographical information into algorithmic equations that provide a more objective approach in describing a bullet's individual and unique characteristics as viewed by the examiner on the comparison microscope, and ultimately diminish the subjectivity associated with an examiner's opinion.

Although the IBIS BULLETTRAX-3D system provides examiners with the ability to utilize both 2D and 3D features to enhance surface topography features and possibly lead to surface topographical measurements, an additional objective approach can be utilized to enhance the capabilities of this system and offer a discrete probability of successes in relation to experiments where there are two possible outcomes in each trial. In this research the 3D topographical "carpet" was enlarged for each acquired pair of known bullets. Using a transparency overlay with 53 bins of equal size (1" by 3/8") each "carpet" was then analyzed based on whether it had any matching seating mark striations in agreement between the original fired projectile and the reseated pulled projectile. One mark indicating a positive result was placed by each bin containing at least one matching striation in order to reduce subjectivity normally associated with an examiners microscopic analysis and the results were tabulated.

CHAPTER 4

Analysis of the Data

Research question #1: Is it possible to identify a bullet back to a cartridge case under both conventional and polygonal methods of firing? The data reveal the answer to be yes with the use of sound methodology; however each case is independent and may have issues that interfere with the ability of an examiner to link these striations back to a cartridge case. For instance, the methodology of preparing a pristine bullet to be reinserted into a known fired cartridge case can be an effective way of reproducing seating marks. Previous research has indicated various methods by which this process may take form. One evident factor found in this research is seating a pristine bullet into a previously fired and resized cartridge case is not completely realistic in relation to factory loading of ammunition. Problematic issues that may promote more stria or multiple sets of striae on a pristine bullet as it is reseated into a previously fired and resized cartridge case may occur due to the resized cartridge being smaller than the pristine bullets diameter. Pressing the bullet into the cartridge case one way and then kinetically pulling it out may also create over marking or distorted striae as well. However, this research revealed that coarse and indented striations were more useful when seeking visual consistencies on both the pulled and fired bullets under microscopic examination.

In regards to firing in a conventional rifled barrel in comparison to a polygonal fired barrel, no distinct differences were noticed among the quality of marks present on the bullets loaded in nickel plated cartridge cases. However, similar effects related to the distortion and lack of individual marks was apparent on all bullets loaded in steel and brass cartridge cases. In addition the data revealed that where a cartridge case and bullet are found but the bullet (i.e. polygonal or conventional fired) cannot be identified solely on the basis of significant striae as generally seen in cases, seating marks are a viable source of identification. Where a typical case of this nature may go cold due to no gun being found or the inability to link the bullet to the cartridge case, seating mark identification provides an additional investigative link.

The data confirmed how relatively rare the phenomenon of seating mark identification is as Clow (2008) noted due to the over marking nature a bullet has as it exits the cartridge and encounters rifling from the barrel, marks that are imparted on the bullet make seating marks less apparent than distinctive rifling striae. However, rifling is not the only phenomenon associated with the lack of reproducible seating marks. In the examination of the Wolf® brand ammunition, the cartridge cases contain a polymer coating that is suppose to support feeding and extraction processes. In this research, this polymer coating may have been the feature on this ammunition that catered to the lack of markings present. The data in this research revealed out of 160 rounds of ammunition, divided among 4 common brands, seating marks were successfully reproduced in over half of the selected tests. Furthermore, identifications were executed and captured both 2 dimensionally and 3 dimensionally on over 26 comparisons of known matched pairs of pulled versus fired tests.

In addition, these data further confirmed results of Clow (2008) and Levine and Kuehner (1998) that Remington Golden Saber .40 S&W caliber 180 grain Jacketed Hollow Point ammunition with a brass jacketed projectile and a nickel cartridge case consistently reproduce seating marks suitable for examination purposes. At the same time these date revealed that Hornady TAP .40 S&W caliber 180 grain Jacketed Hollow Point ammunition with a copper jacketed projectile and a nickel cartridge case also consistently reproduce seating marks suitable for examination purposes; whereas Wolf brand 40 S&W caliber 180 grain Full Metal Jacket (Bi-Metal) with a copper jacketed projectile and a steel cartridge case and Federal brand 40 S&W caliber 165 grain Full Metal Jacket with a copper jacketed projectile and a brass cartridge case rarely produce suitable seating marks.

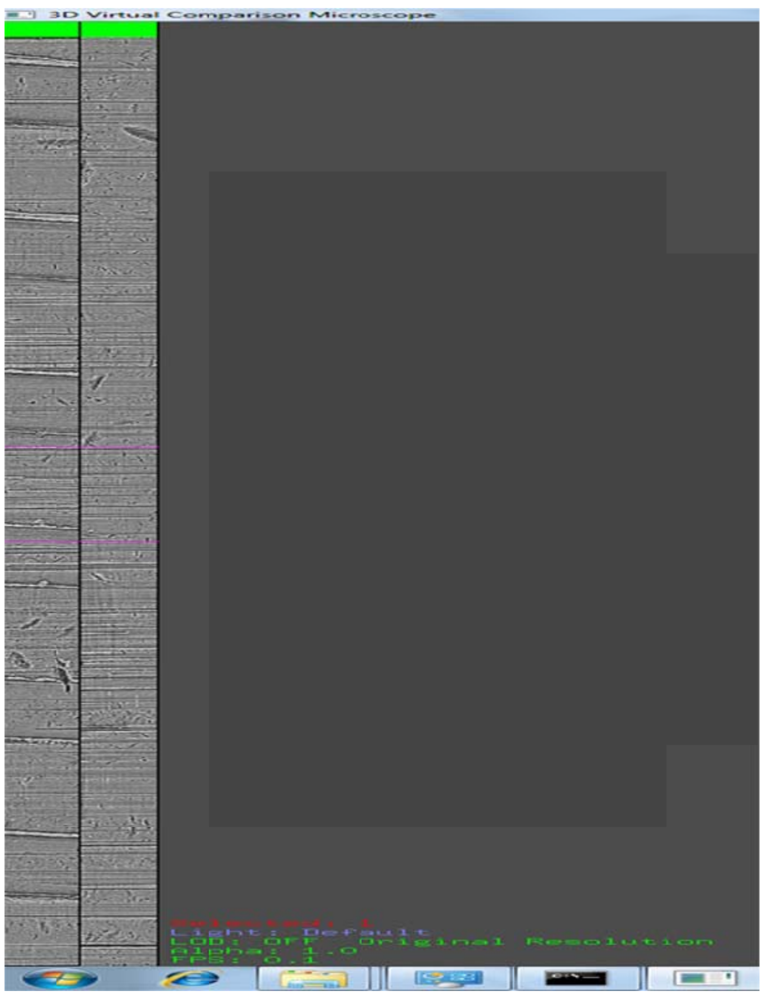
Factors that attributed to the ability to link cartridge cases to bullets within this research were similar to previous methods described in research that relate to an examiner's ability to successfully produce exemplar bullets for comparative analysis in casework as well as research. The factors of orienting both the cartridge case and bullet for equivalent starting points for microscopic analysis supported consistent, repeatable, and reliable methods for each test component.

Research question 2: What brands of ammunition present quality seating marks useful for examination purposes? Test samples in this research revealed a higher likelihood for the researcher to view abundant sets of striae on ammunition brands containing nickel cartridge cases and copper jacketed bullets or nickel cartridge cases with brass jacketed bullets. The data revealed that material hardness is the crucial factor in the likelihood that the metal's composition will mark or indent another; specifically when dealing with cartridge cases and bullets. However, it was revealed that material hardness is not a singular factor in the ability for one composition to mark another as seen with the rarity of marks on the Wolf® brand ammunition. One evident dynamic was the variation in random imperfections/burrs on cartridge case mouths of different compositions. The effects of tumbling or other finishing processes on trimmed cartridge cases during the manufacturing processes in some cartridge cases were an inhibiting factor in relation to the striae located on the bullets. Many test samples (i.e. pulled vs. fired bullets) in this research that contained copper jacketed bullets loaded into brass or steel cartridge cases picked up few, if any striae from the case mouth burrs, whereas copper jacketed bullets and brass jacketed bullets loaded into nickel plated cases picked up significant identifying marks. Some of these factors may be related to the microhardness of the metals utilized in this research.

The ammunition brands and compositions that directly relate to what brands of ammunition present quality seating marks useful for examination purposes include the Remington Golden Saber™ .40 S&W caliber 180 grain Jacketed Hollow Point ammunition with a brass jacketed projectile and a nickel cartridge case. In addition, the Hornady TAP .40 S&W caliber 180 grain Jacketed Hollow Point ammunition with a copper jacketed projectile and a nickel cartridge case.

Research question #3: Is there an objective approach for interpreting firearm examiner conclusions derived from microscopic examination? Data obtained in this research revealed that by utilizing the IBIS BULLETTRAX-3D's sensor capturing technology to enhance the quality of the images visually seen during microscopic comparison the 3D-viewer prototype allows the user to compare a flat scale 1.6mm band "carpet" of the captured surface topography of multiple bullets (see *figure 7*). This captured topography reveals the ability for this technological tool to assist an examiner in determining objective methods for analyzing and quantifying a bullets overall features and may aid in objective statements that indicate higher degrees of certainty in addition to the visual microscopic detail often described by examiners.

Figure 7.



One facet revealed in this research was the ability for IBIS BULLETTRAX-3D™ system to serve as a confirmation tool for subjective conclusions derived from characteristics visualized through microscopic examination. In addition, the use of a 3D viewer enhances the feasibility for examiners to utilize a more objective representation to describe and defend opinions rendered during microscopic examination. Beauchamp (2010) reported that 3D data provides better matching and visualization performance than standard 2D data. His research revealed that innovative technology such as the IBIS BULLETTRAX-3D™ system and viewer may enhance subjective processes, and assist examiners in being more effective and efficient.

The following figures represent known match pairs acquired utilizing the IBIS Heritage 2D capturing technology in comparison to BULLETTRAX-3D's sensor capturing technology. Side by side images are provided that show 2 dimensional captured images using IBIS Heritage 2D technology and IBIS BULLETTRAX-3D™ technology of fired bullets of different compositions with significant striae. Additional images indicate the differences in visualization quality of 2D and 3D representations of bullets captured with different compositions as they are inter-compared. It should be noted that these images indicate the extent and quality of characteristics that are revealed as information is acquired using this technology. In addition, the overall quality of the images as seen with the IBIS BULLETTRAX-3D technology provides an improved visual representation for comparison of the known match pairs acquired in this study. As derived from results in a previous study on IBIS 3D visualization performance, it was concluded that 3D data provides a much better environment for matching and visualizing striae regardless of a components composition (A. Beauchamp, 2010) (see *Figures 8 -13*).

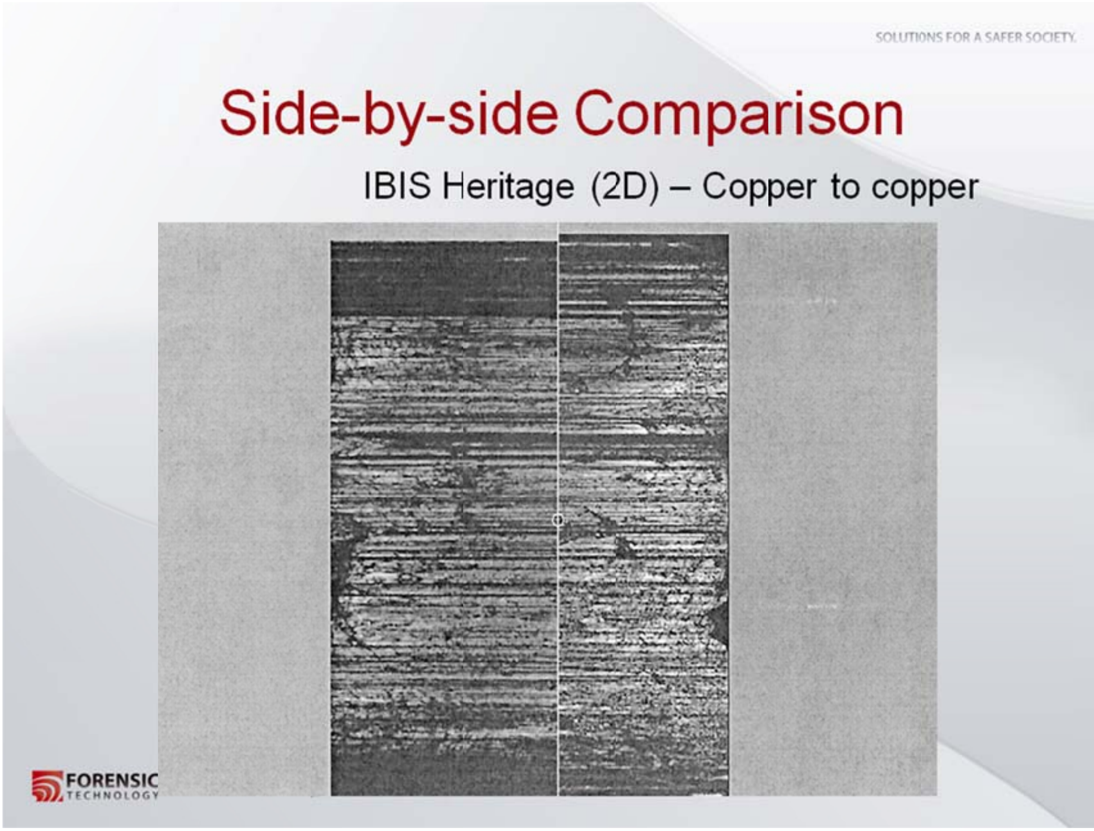


Figure 8.

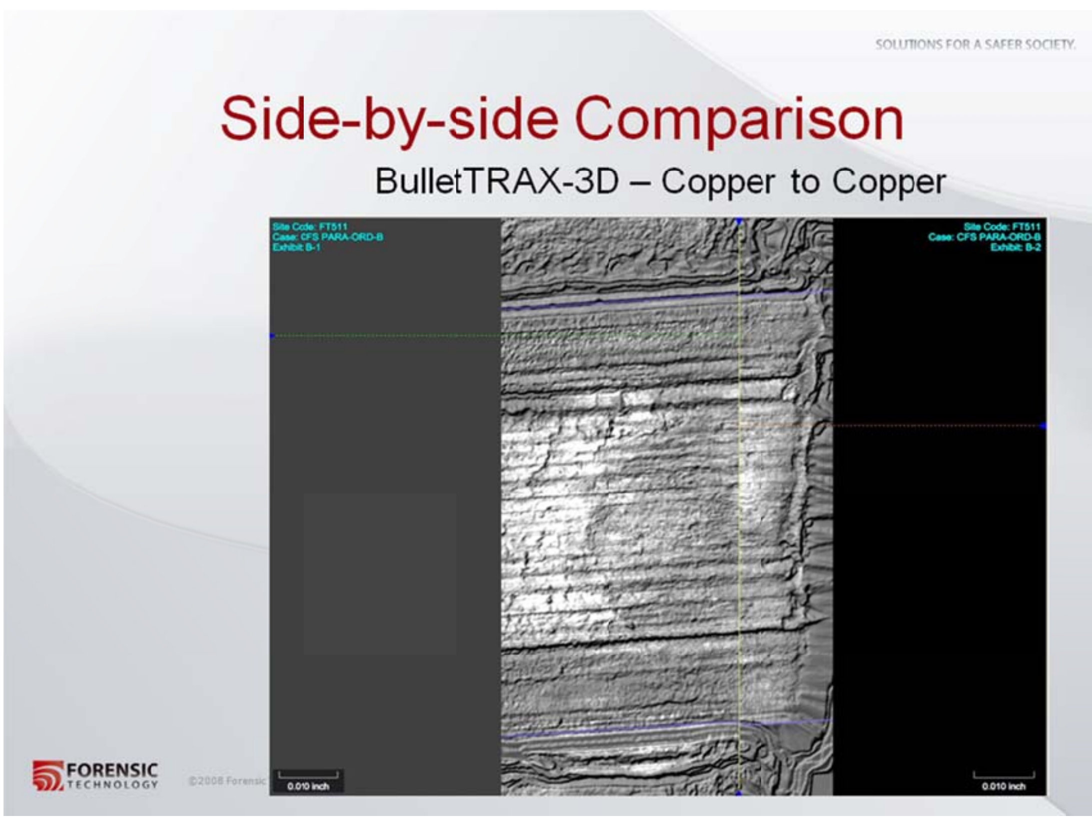


Figure 9.

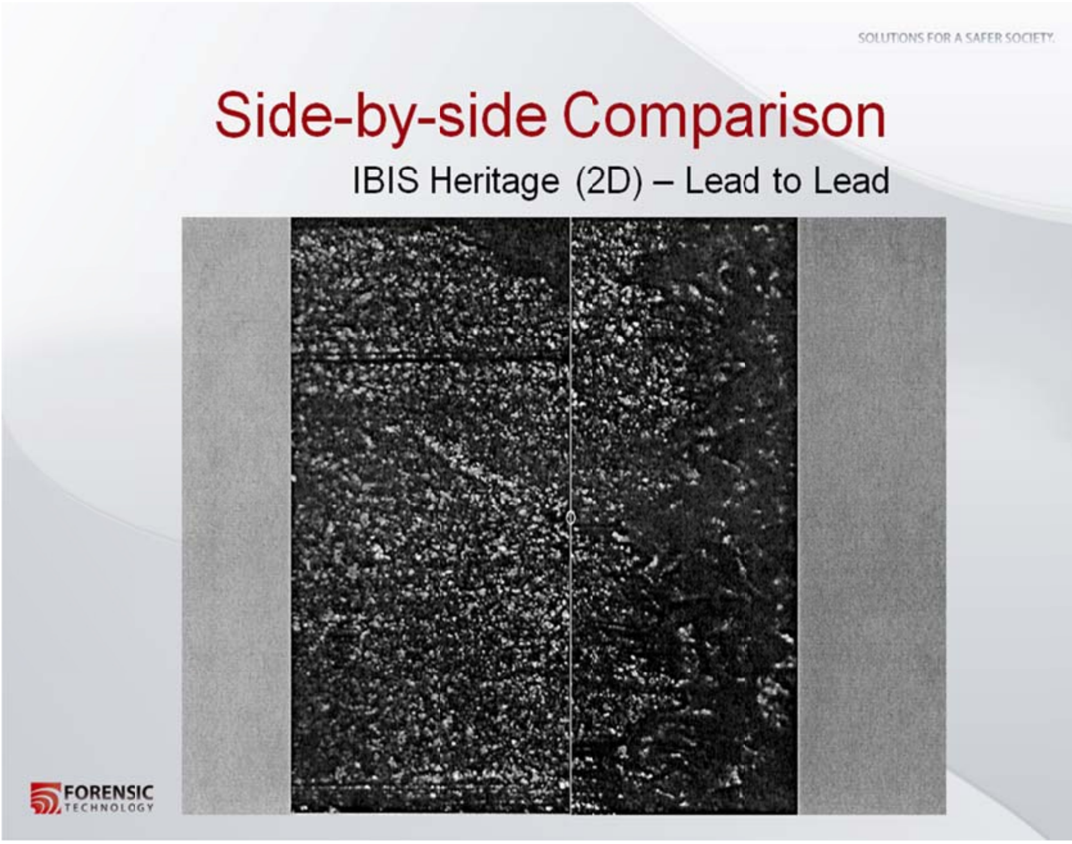


Figure 10.

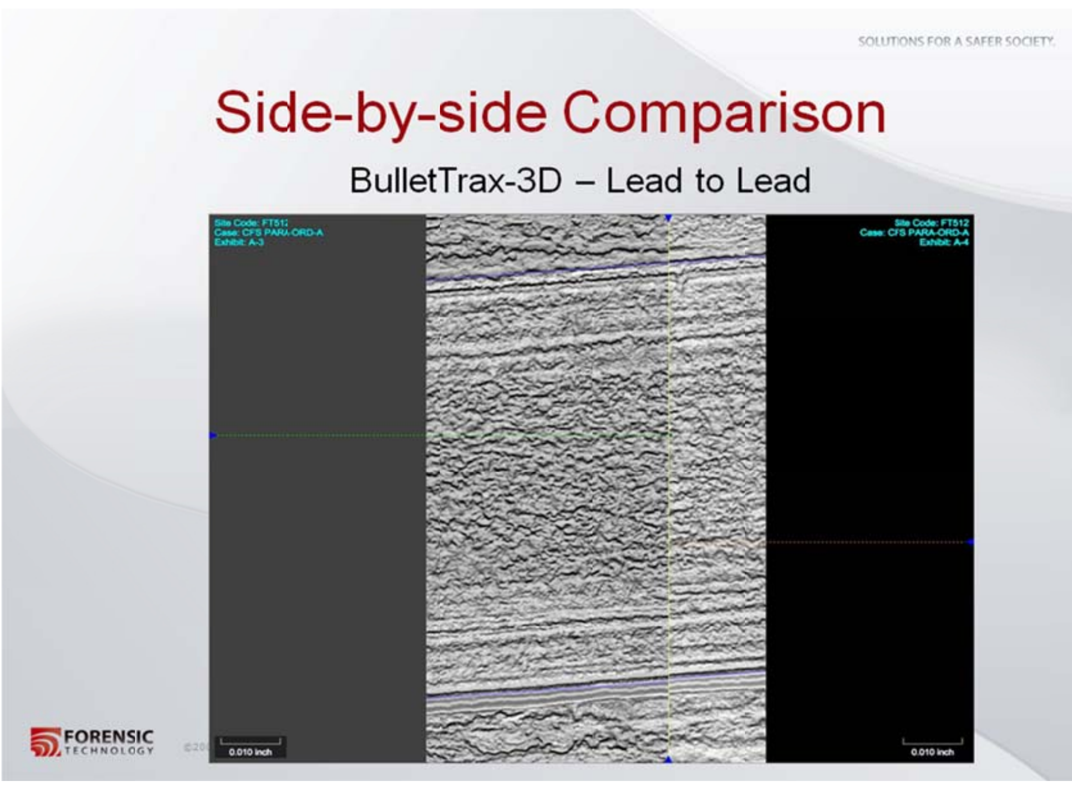


Figure 11.

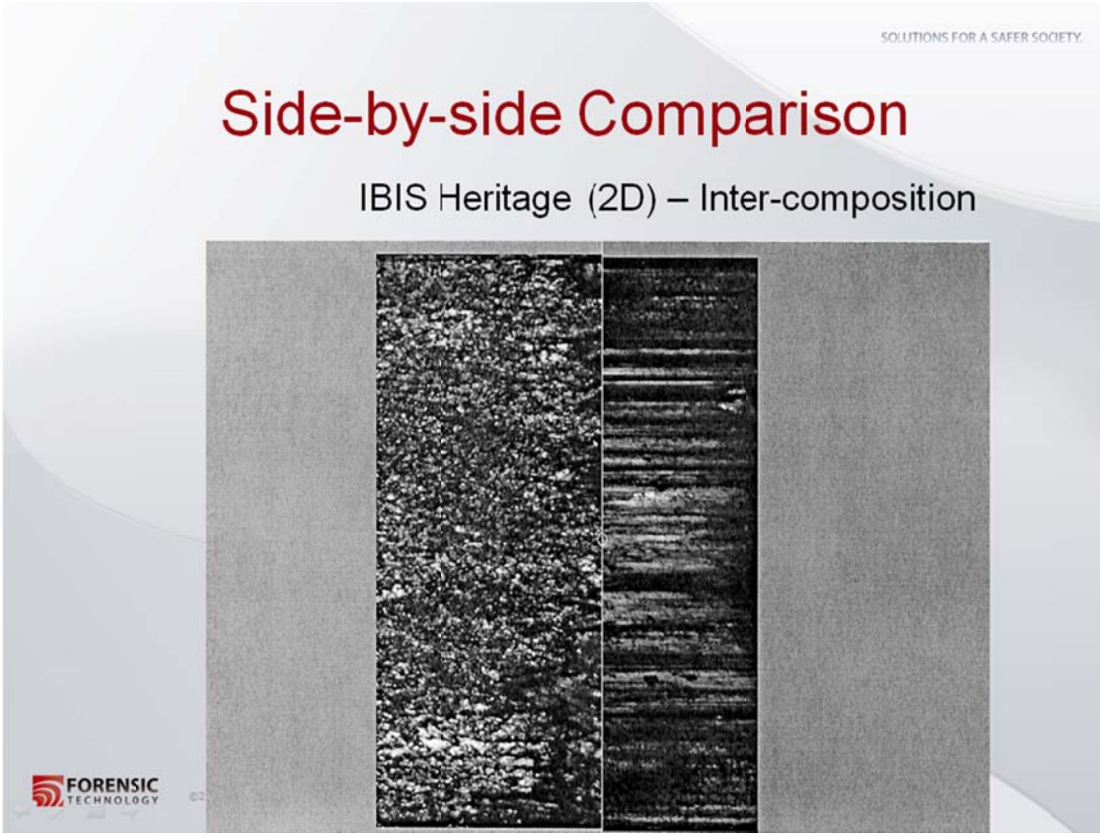


Figure 12.

Figure 13.

The following figures represent images of the known matched pairs captured in this study on the comparison microscope and utilizing the IBIS BULLETTRAX-3D technology (see *Figures 14-23)*. Each figure contains two images described as comparison microscope (CM) or IBIS BULLETTRAX-3D (IBT), ammunition brand name (i.e. Remington Golden Saber- RGS or Hornady TAP- HTAP), firearm type (i.e. Beretta or Glock), and item number. The image on the left is a 2D representation of significant striations suitable for identification purposes as viewed on the comparison microscope of one fired bullet with seating marks and one pulled bullet with seating marks. While this representation is often considered a 3 dimensional view on the comparison scope, there are no formal methods of capturing this information in 3D format on a comparison scope; therefore limiting the ability to see the variation in characteristics and detail as viewed by the examiner. The second image is a 3D representation of two 1.6mm band regions of interest on the same two bullets seen in the 2D representation. These 3D representations provide viewers the ability to see the entire circumference of the bullet and the full amount of detail associated with each individual striae. The quality of detail associated with images of this caliber provides potential for more objective methods to represent what is viewed on the comparison microscope. The microscopic details, including the shoulders, are significantly enhanced in some of the figures when the "alpha factor" has been applied.

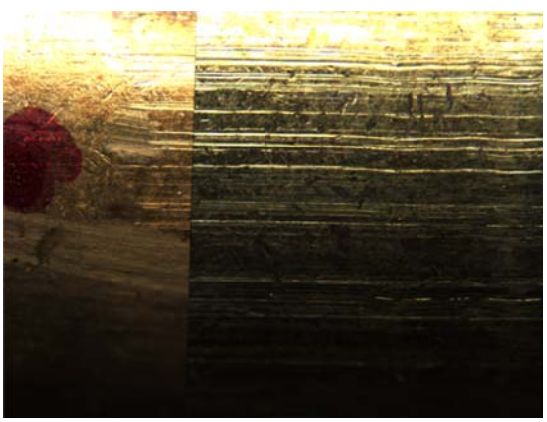
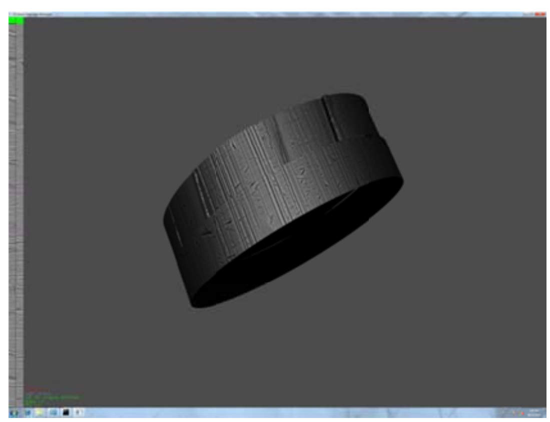
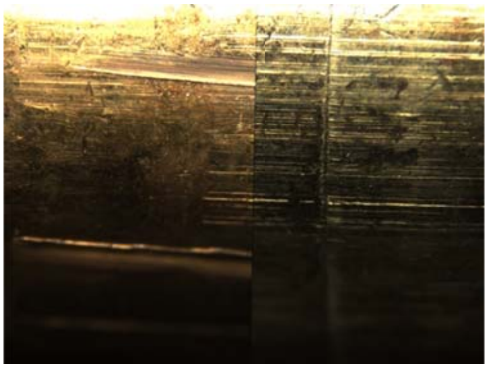


Figure 14. CM RGS Beretta (2) fired to pulled



IBT RGS Beretta (2) fired to pulled



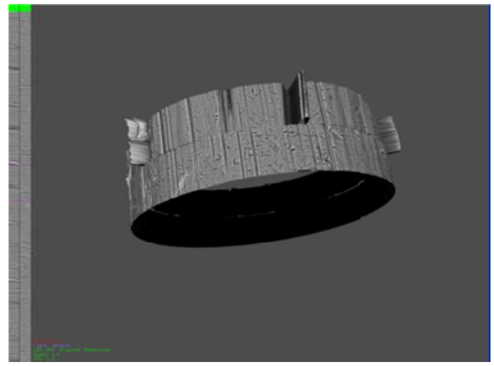
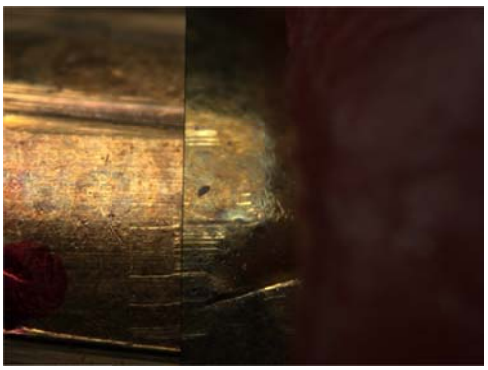


Figure 15. CM RGS Beretta (5) fired to pulled IBT RGS Beretta (5) fired to pulled



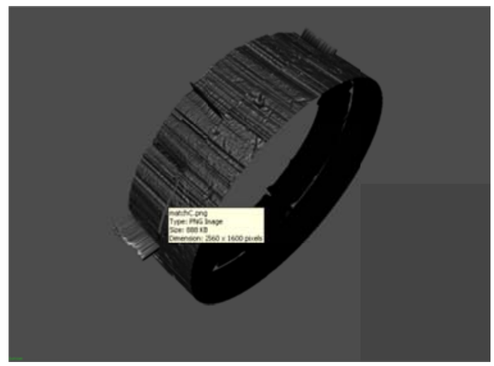
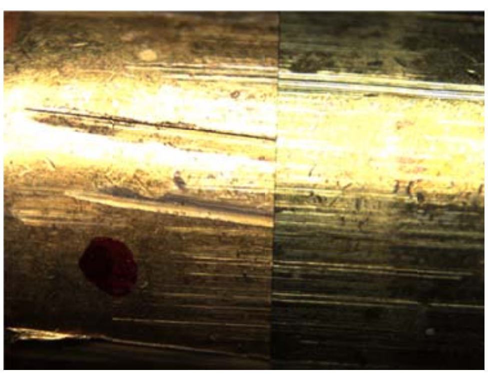


Figure 16. CM RGS Beretta (8) fired to pulled IBT RGS Beretta (8) fired to pulled



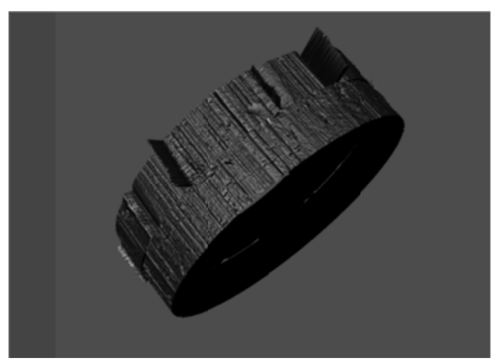


Figure 17. CM RGS Glock (1A) fired to pulled IBT RGS Beretta (1A) fired to pulled

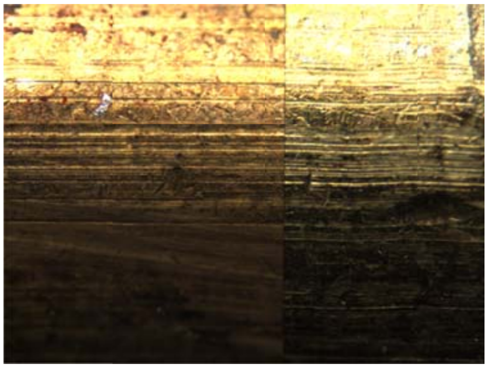



Figure 18. CM RGS Glock (5A) fired to pulled IBT RGS Beretta (5A) fired to pulled

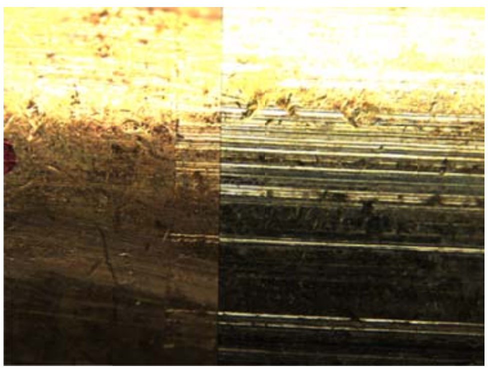
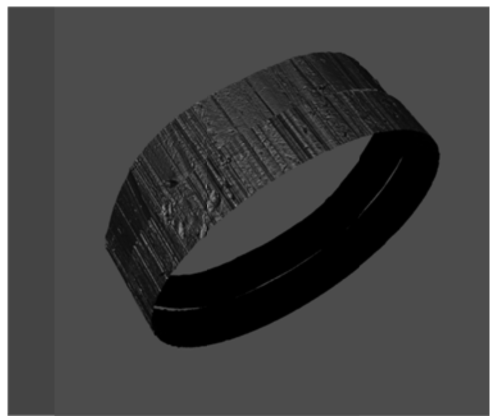



Figure 19. CM RGS Glock (8A) fired to pulled IBT RGS Beretta (8A) fired to pulled

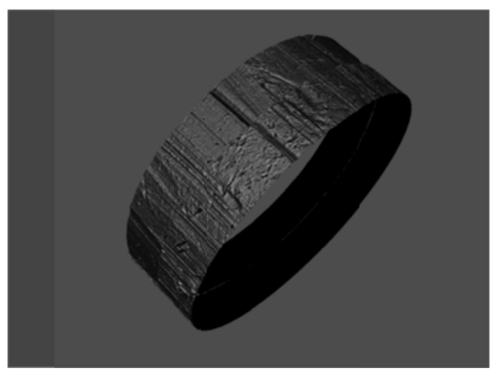



Figure 20. CM RGS Glock (9A) fired to pulled IBT RGS Beretta (9A) fired to pulled

Figure 21. CM RGS Glock (6A) fired to pulled IBT RGS Beretta (6A) fired to pulled

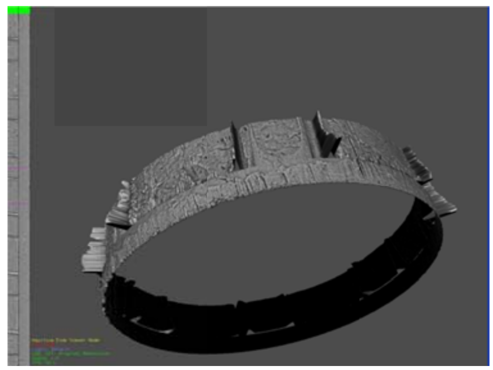


Figure 22. IBT HTAP (10) fired to pulled

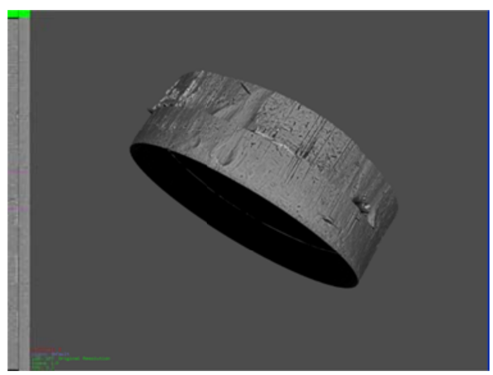


Figure 23. IBT HTAP (poly25) fired to pulled

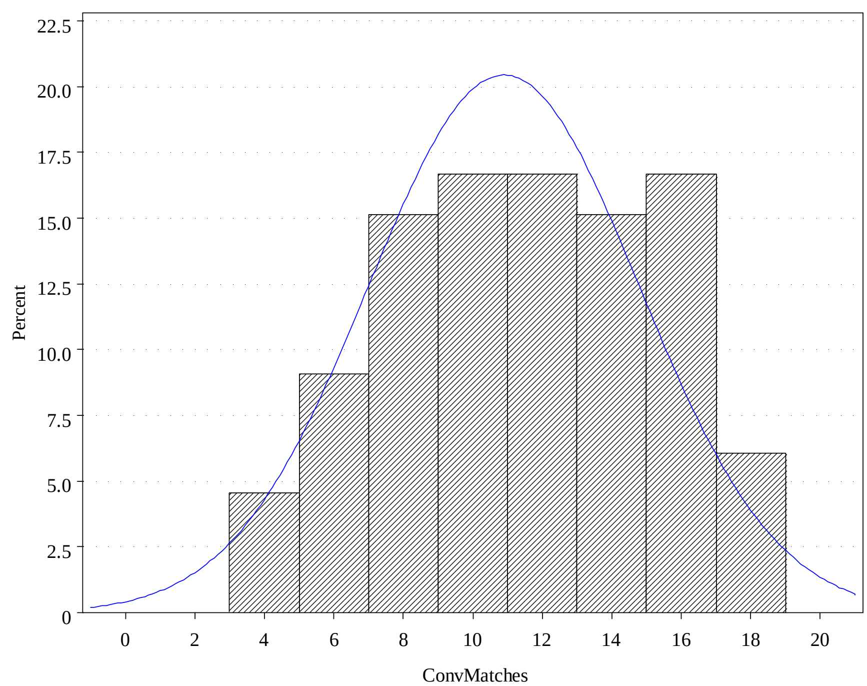
In order to indicate this system's 2D and 3D performance for providing examiners with the ability to quantify data as it relates to linking samples whether known to match or unknown, binomial probabilities and likelihoods for a restricted sample were calculated.

Through the use of the IBIS BULLETTRAX-3D^{TM} system and its sensory capturing technology, 13 total bullet pairs were analyzed and key surface topographical features were obtained. It was established through this research that by using 53 fixed bins for comparison purposes, more objective conclusions can be reported. In the binomial distribution formula used in this research the probability of a positive result (*p*) in any random pair of side by side bins was estimated to be approximately 0.14 for conventional fired bullets and approximately 0.08 for polygonal fired bullets, using the method described in chapter 3. The number of bins used in any given comparison was 53 (*n)* and the number of positive results (*x*) was determined based on the side by side bins that contained at least one matching striation when the two topographical carpets were in best fit positions. The researcher then used either SAS version 9.1 or R version 10.2.1 to calculate the probability of getting at least as many matches as observed in each pair of bullets. To find the likelihood this researcher divided 1 by this probability.

This research analyzed twelve non-matching conventional and polygonal bullets. All possible pairs of bullets (66 conventional and 66 polygonal) were analyzed. The data reveal that in known non-matching pairs of fired to fired conventional bullets the mean number of matches observed in any two bullets at random was 10.89 which indicates when viewing conventional known non-matching pairs of bullets only approximately 21% of bins will be in agreement using the proposed methodology. Whereas in fired to fired conventional known matches the mean number of matches observed in any two bullets at random was 46.57 which indicates when viewing conventional known matching bullets approximately 88% of bins will be in agreement using the proposed methodology. In addition, for known non-matching pairs of fired to fired polygonal bullets the mean number of matches observed in any two bullets at random was 2.35 which indicates when viewing known non-matching polygonal bullets approximately 4% of bins will be in agreement using the proposed methodology; whereas in fired to fired polygonal known matches the mean number of matches observed was 41.00 which indicates when viewing polygonal known matching bullets approximately 77% of bins will be in agreement when using the proposed methodology (see table 1.0 Fired to Fired Summary Statistics).

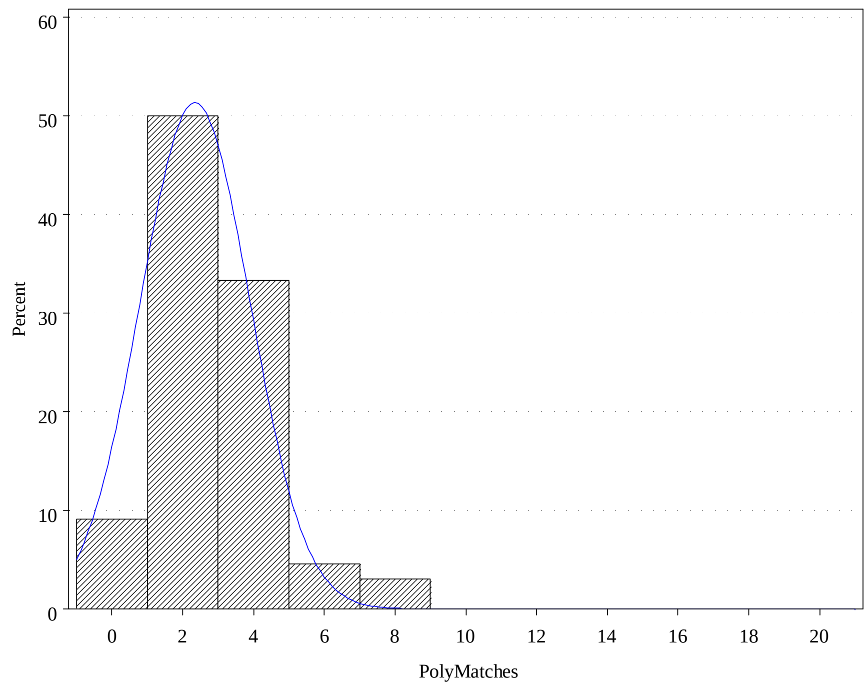
Based on the data obtained in this research, histograms were produced for both fired to fired and pulled to fired conventional and polygonal bullet comparisons. For each histogram shown a normal distribution overlay has been applied to indicate a graphical summary of the shape of the data's distribution. The shapes of the following distributions (Figures 24 – 27) convey that it is reasonable to assume a binomial distribution exists as seen by viewing the frequencies that extend beyond the normal distribution overlay.

Figure 24. Histogram of Fired to Fired Conventional Comparisons



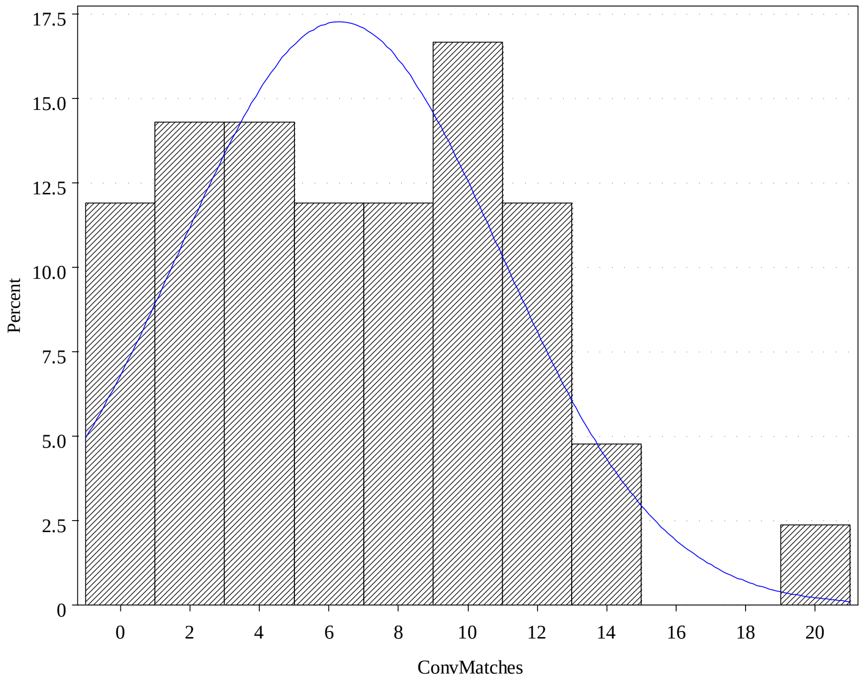
This histogram shows an approximate binomial distribution with a normal distribution overlay for the number of matching bins in fired to fired conventional bullet comparisons.

Figure 25. Histogram of Fired to Fired Polygonal Comparisons



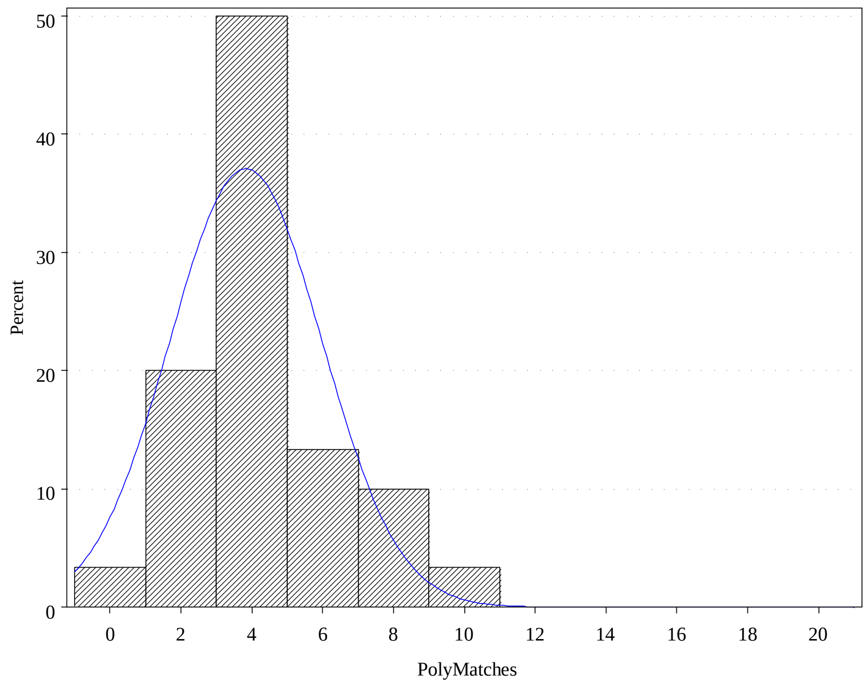
This histogram shows an approximate binomial distribution with a normal distribution overlay for the number of matching bins in fired to fired polygonal bullet comparisons.

Figure 26. Histogram of Pulled to Fired Conventional Comparisons



This histogram shows an approximate binomial distribution with a normal distribution overlay for the number of matching bins in pulled to fired conventional bullet comparisons.

Figure 27. Histogram of Pulled to Fired Polygonal Comparisons



This histogram shows an approximate binomial distribution with a normal distribution overlay for the number of matching bins in pulled to fired polygonal bullet comparisons.

Table 1.0 (Fired to Fired Summary Statistics *by SAS version 9.1***)**

	N	Mean	Std. Dev.	Range
Conventional				
Non-Matches	66	10.89	3.9	3-18
Matches	7	46.57	2.76	43-50
Polygonal				
Non-Matches	66	2.35	1.55	0-7
Matches	6	41.00	5.87	31-48

The assessment of the data when examining the known matching pairs of pulled to fired conventional bullets reveal substantial likelihoods in six out of seven pulled to fired comparisons. On the contrary, calculations reveal high probabilities and relatively small likelihoods when examining known matching pairs of pulled to fired polygonal bullets (see table 2.0).

Table 2.0 (Known Matching Pairs of Pulled to Fired Bullets *by SAS version 9.1***)**

	Pulled Bullet	Fired Bullet	Matches	Probability	Likelihood
Conventional	1	1	33	9.992×10^{-16}	1.001×10^{15}
	2	2	23	2.414×10^{-7}	4.143×10^{6}
	3	3	30	7.313×10^{-13}	1.367×10^{12}
	4	4	30	7.313×10^{-13}	1.367×10^{12}
	5	5	28	3.980×10^{-11}	2.513×10^{10}
	6	6	32	9.992×10^{-15}	1.001×10^{14}
	7	7	4	0.9535	1.0487
Polygonal	1	1	14	1.001×10^{-4}	9.990×10^{3}
	2	2	13	3.888×10^{-4}	2.572×10^{3}
	3	3	21	6.927×10^{-10}	1.444×10^{9}
	4	4	14	1.001×10^{-4}	9.990×10^{3}
	5	5	4	0.6691	1.495
	6	6	5	0.4722	2.118

A similar procedure was used to determine the probabilities and likelihoods when comparing fired conventional bullets to fired conventional bullets and fired polygonal bullets to fired polygonal bullets. In this case, the probability of a positive result (p) in any random pair of side by side bins was estimated to by approximately 0.22 for conventional fired bullets and approximately 0.05 for polygonal fired bullets. The resulting likelihoods are considerably large for both conventional and polygonal bullets (see table 3.0).

Table 3.0 (Known Matching Pairs of Fired to Fired Bullets *by R version 2.10.1***)**

	Fired Bullet	Fired Bullet	Matches	Probability	Likelihood
Conventional	1	1	50	$1.735 x 10^{-29}$	$5.764 x 10^{28}$
	2	2	44	$6.636 x 10^{-21}$	$1.507 x 10^{20}$
	3	3	47	$7.634 x 10^{-25}$	$1.310 x 10^{24}$
	4	4	45	$3.729 x 10^{-22}$	$2.682 x 10^{21}$
	5	5	50	$1.735 x 10^{-29}$	$5.764 x 10^{28}$
	6	6	47	$7.634 x 10^{-25}$	$1.310 x 10^{24}$
	7	7	43	$1.040 x 10^{-19}$	$9.620 x 10^{18}$
Polygonal	1	1	39	$2.795 x 10^{-39}$	$3.578 x 10^{38}$
	2	2	31	$8.799 x 10^{-27}$	$1.136 x 10^{26}$
	3	3	40	$5.175 x 10^{-41}$	$1.933 x 10^{40}$
	4	4	44	$2.137 x 10^{-48}$	$4.680 x 10^{47}$
	5	5	44	$2.137 x 10^{-48}$	$4.680 x 10^{47}$
	6	6	48	$1.086 x 10^{-56}$	$9.210 x 10^{55}$

It is interesting to note that when comparing the maximum number of matching bins as reported in Table 1.0 (18 for conventional, 7 for polygonal) for known non-matches of fired to fired bullets, we would expect 1 in 31.65 conventional bullets selected at random to have at least 18 matching bins, and 1 in 60.53 bullets selected at random to have at least 7 matching bins.

The analysis of the thirteen pulled to fired acquired bullets (7 conventional and 6 polygonal) selected for this research were analyzed based on the method of firing. For the conventional known non-matches all possible pairs of bullets (42) were compared and the mean number of matches observed was 6.31 which indicates when viewing conventional known non-matching bullets approximately 12% of bins will be in agreement using the proposed methodology. Seven comparisons were conducted for the pulled to fired conventional known matching bullets and the mean number of matches was 25.71 which indicates when viewing conventional known matching bullets approximately 49% of bins will be in agreement using the proposed methodology. For the polygonal known non-matches all possible pairs of bullets (30) were compared and the mean number of matches observed was 3.83 which indicates when viewing polygonal known non-matching bullets approximately 7% of bins will be in agreement using the proposed methodology. Six comparisons were conducted for the pulled to fired polygonal known matching bullets and the mean number of matches observed was 11.83 which indicates when viewing polygonal known matching bullets approximately 22% of bins will be in agreement using the proposed methodology (see Table 4.0 pulled to fired summary statistics).

Table 4.0 (Pulled to Fired Summary Statistics *by SAS version 9.1***)**

	N	Mean	Std. Dev.	Range
Conventional				
Non-Matches	42	6.31	4.62	0-19
Matches	7	25.71	10.11	4-33
Polygonal				
Non-Matches	30	3.83	2.15	0-9
Matches	6	11.83	6.37	4-21

It is interesting to note that when comparing the maximum number of matching bins as reported in Table 4.0 (19 for conventional, 9 for polygonal) for known non-matches of pulled to fired bullets, we would expect 1 in $1.468x10^4$ conventional bullets selected at random to have at least 19 matching bins, 1 in 30.04 polygonal bullets selected at random to have at least 9 matching bins.

CHAPTER 5

Discussion

The identification process within firearm and tool mark examination, while subjective in nature, has progressed rapidly over the past century, yet the discipline has faced several criticisms associated with its inability to utilized objective methods for describing conclusions as observed by examiners. The purpose of this research was to provide new methods in 2D/3D analysis and interpretation that enhances the ability for examiners to utilize more objective methods during examinations. Examiners are faced with challenging tasks such as linking cartridge cases to bullets. While previous research has explored matching a bullet to a cartridge case utilizing various methods for reproducing seating marks and identifying factors such as material hardness and manufacturing processes as being critical factors in successfully linking the two items, little research has explored technological approaches that provide a means to quantify what is viewed by the examiner.

The purpose of this study was to determine the possibility of identifying a bullet back to a cartridge case under both polygonal and conventional firing methods. Additional objectives were to determine which brands of ammunition produced seating marks suitable for comparison purposes, and to determine if a more objective approach for interpreting Firearm examiner identifications exists. Both qualitative and quantitative results provided by this research addressed concerns that have been outlined by the National Academy of Sciences (2009). Specifically this research addressed appropriate methods for (a) developing a proper test method for acquiring seating mark information (striations) from known match pair samples; (b) utilizing topographical information as a basis for objectively identifying seating marks on bullets and (c) ultimately quantifying this information to provide examiners with an objective approach of surface topography identification of bullets.

Major factors that promoted an increase in seating marks on the Hornady and Remington ammunition and related to the overall conclusion drawn to research question one was material hardness of the cartridge case in comparison to that of the bullet. Although research has shown that material hardness is a contributing factor in cases where seating marks or other marks may be seen, there were instances in which known match pairs of Wolf and Federal brand ammunition contained seating marks suitable for examination, however insufficient for identification purposes. In many instances, it was noted that rifling had little to no additional effect on the quality of marks exhibited on the Hornady and Remington brand ammunition. One worthy conclusion derived based on the observations in this study was that seating marks produced remained apparent even after firing in both rifling types on a diverse amount of known match pairs across all four ammunition types. Examiners should examine marks within the rifling, but also look at horizontal striations such as seating marks as additional support in linking or identifying components.

This research indicated that nickel plated brass cartridge cases have a higher tendency to produce suitable seating marks in comparison to the Federal and Wolf brand ammunition selected in this study. It is reported that nickel electroplated brass has a Vickers microhardness value of 157 - 186 kg/mm^2, while brass has a Vickers microhardness value of 108 – 114kg/mm^2 (Tulleners, 2003). The National Institute of Standards and Technology Website reports copper as having a microhardness of 125kg/mm^2 and Foll (2010) reports mild steel as having a Vickers microhardness of 140 kg/mm^2. These values indicated that as one metals hardness increases the likelihood it will mark another of lesser value should also increase. No attempts or conclusions should be drawn based on the wide variety of ammunition brands available on the market in relation to the observations of this study. While material hardness, as previously stated, may have been a contributing factor in producing sufficient seating marks it should be noted that all known match pairs were not sufficient for identification. In addition, the method of production selected for this study indicated the most probable situation that may occur should a cartridge case be found at a scene along with a bullet that contains seating marks. However, during the research it was noted that the use of a resizing die proved beneficial when producing test specimen for comparison. While this may not always be an available method for the production of test specimen in a laboratory setting, this researcher found that utilizing repeatable practices diminished the likelihood that inconsistencies would result over the four brands selected.

In relation to research question three and the overall intent of this study, this research indicated a more objective method and approach for interpreting conclusions derived in firearm and tool mark examinations. It was established through this research that the IBIS BULLETTRAX-3D technology within this system can assist in capturing patterns and unique individual striae while enhancing them for an even better visualization experience than typically seen on a comparison microscope. Tactically implementing such technology into objective results may be of immediate value for one case but could potentially spark a series of similar events in this field of expertise. Strategically, this technology and data within this research could be collected over time and be utilized to better define characteristic features such as a striation, potentially serve as a topographical GPS tool for courtroom exhibits, and in the future assist in supplementary advances for linking components together.

One major implication that this research conveys is the ability for advancement within the community of firearm and tool mark examination in relation to other disciplines such as DNA. For years firearms and tool mark analysis and other subjective, physical, or applied forensic disciplines have been labeled as less objective than others. It should be understood the most important aspect here is to pursue an approach that aggressively acknowledges that there are dilemmas related to the interpretation of individualizations or identifications being subjective in nature. While at the same time it is just as important to incorporate technology and processes that will help bridge the gap among subjective opinions and move toward more objective procedures in an overall effort to continue on the path of assisting the field of firearm and tool marks.

In this research the statistics and likelihoods presented indicate several important aspects related to seating marks and the overall ability for firearm examiners to utilize objective methods for determining how rare it may be to find another bullet with substantial markings when a conclusion of identification is reached. While the numbers in *Table 2.0* and *Table 3.0* are rather large they indicate the rareness of finding another bullet or bullets with unique seating marks or striations that may ever be observed as a match. While the known matching pair likelihoods in *Table 2.0* and *Table 3.0* indicates the ability for examiners to quantify characteristics through observation. As shown in *Table 2.0 and Table 3.0* the data reveal the plausibility that another bullet, selected at random, would have at least as many matching bins as viewed in this research. In addition this data further identifies how unique a bullet's topography really is in comparison to two bullets being selected at random as shown in *Tables 1.0 & 4.0.*

In known non- matches and known matches of pulled to fired bullets it can be clearly stated that while the likelihoods reported are generous, when compared to the likelihoods of fired to fired bullets it is apparent how minute pulled to fired likelihoods really are. For examiners this indicates that while pulled to fired bullets may be compared and matches may be found, in some instances there may be limited matches observed which indicate the need for the examiner to be more conservative. The data reveal that regardless of the firing method or method of comparison bullets known to match carry a much higher percentage of agreement than randomly selected non-matched bullets. In addition, the data also specifies that seating marks, even when reproduced in casework for comparison purposes may not reveal substantial markings that will be observed by examiners and therefore should be utilized in relation to other significant striations and characteristics present, rather than utilized alone when attempting to determine if a bullet was fired from a cartridge case.

The statistics in this study reveal that fired to fired known matching bullets produce substantial markings that provide significant objective criteria that indicate how rare a bullets topography truly is. The size of the likelihoods stated in this research reveal that a bullet's topography and its features can be quantified when appropriate technology and methodology are combined to provide a comparative estimate of a bullet's uniqueness. For example *Table 2.0* indicates that the least unique bullet regardless of method of firing indicates a likelihood of 1 in 1.0487 chance that another randomly selected bullet will have at least as many matches when using the proposed methodology. On the other hand the most unique bullet regardless of method of firing in *Table 2.0* has a likelihood of 1 in 9.990×10^{3}. *Table 3.0* reveals the least unique bullet as having a likelihood of 1 in 9.620×10^{18}, while the most unique bullet has a likelihood of 1 in 9.210×10^{55}. This data reveals that uniqueness among matches carries a rare likelihood in all cases of known matching bullets. In addition, the ability to objectively state how relatively rare it would be for an examiner to select any other bullet at random and observe just as many marks as viewed in this research is very credible to this field of expertise. As stated previously, research like this has the potential to establish a degree of certainty when testifying to the microscopic examination of any bullet.

Limitations

While this research examined three important questions within firearm and tool mark examination and indicated approaches for moving in a more objective direction of interpretation, there were several limitations to this study. The first limitation was related to the acquired sample size utilized in this study. While the acquired sample size of pulled to fired bullets was combined to be thirteen total pairs overall sample size of thirteen acquisitions out of four brands of bullets is small and it is recognized that a larger sample of acquisitions and diverse brands may improve the results stated in this research. The second limitation was that the manufacturing information of each brand could not be obtained. For instance, while much of the manufacturing processes are similar, there may be a more specific reason that the Wolf brand ammunition did not mark the bullets in this study. This may be something as small as a unique finishing process; however, based on previous research, the steel cartridge case should have marked the bullets. Together these limitations have an impact on the internal validity and make the results difficult to generalize in comparison to previous empirical research.

Other limitations in this study are related to the interpretation of the results. It should be understood that two types of interpretation were utilized in this study. Just as the AFTE Theory of Identification explains, the interpretation of an individualization or identification is subjective in nature and relies on the examiners training and experience, this subjectivity is carried on throughout this study.

Even when utilizing a technological tool (IBIS BULLETTRAX-3D^{TM}) to concentrate on the visual aspects related to a bullet's surface topography, the overall interpretation at this point, while a more objective visual approach, still requires an examiners subjective interpretation to describe what is being seen and what this indicates. Furthermore, the quantitative data reported in this study may be viewed as an extreme indication of where objective criteria such as that reported in this study may lead this field of expertise. One limitation in this study that was immediately recognized was the inability to indicate how rare a known match truly is in comparison to a known non-match. Currently the likelihoods as stated in this study indicate numbers that are much larger than those spoken of in DNA analysis. The need to determine what the term "rare" truly means in relation to the likelihoods reported would be a great area for future research.

Firearm and tool mark analysis is a subjective, physical, and applied discipline of forensic expertise which acknowledges that everyone does not have the same amount of training and experience and nowhere has it ever been stated that opinions be rendered only when two surface contours are exactly the same. The above limitations may have affected the internal validity of the results and this researcher acknowledges with a larger acquisition sample size, diverse ammunition brands, and advancements to include quantifiable data through the current technology provided by the IBIS BULLETTRAX-3D^{TM} system, conclusions derived in this field of expertise may have a greater impact in the future.

Recommendations for Future Research

The results of this study lend several recommendations for future research. First some of the limitations outlined in this study may be eliminated should technological advances with the IBIS BULLETTRAX-3D system be improved and implemented. Implementation of this tool could provide several advancements in how firearm-related data and interpretation is viewed, verified, analyzed and presented in a court of law. In addition in order to continue to identify which brands of ammunition produce seating marks which are suitable for examination purposes, additional brands could be introduced. Third, this study was unable to define how rare a known match is in comparison to a known non-match. Through the use of summary statistics it is reported that when a known match is observed it is very rare that another bullet would be found and observed by another examiner with as many marks. However, limited information is known at this point of where to set the bar between known matches and known non-matches in relation to a plausible population. This could be a great advancement in this area of objective research. Future studies should employ suitable samples sizes of both known match pair samples and known non-match pair samples which may take the population of all acquired bullets in the database into consideration to firmly establish statistical likelihoods and ultimately identify the accuracy of this technology in relation to the bullets it acquires.

Conclusion

The present study presented interesting findings within the area of linking bullets to cartridge cases and deriving more objective findings in relation to subjective opinions derived during examination. First, the preponderance of seating marks found on over half of the sample size in this study indicates the reality that seating marks are a unusual occurrence but may be utilized to link a bullet to a cartridge case in several situations should they arise in casework. Clow (2008) indicates that scenarios such as these may occur in a setting where one bullet is linked to a cartridge case, which ultimately links all components on one case to one specific firearm. In addition, cartridge cases that are submitted on a case and found to be inconclusively identified to one another, but the bullets are identified, stand the likelihood at being linked back to their respective cartridge cases and potentially provide support that one gun fired all the components submitted on that case. Finally Clow (2008) states when all components, both bullets and cartridge cases are found to be inconclusively identified there is the potential to link bullets to cartridge cases and possibly diminish the likelihood that there may be multiple firearms. A greater awareness of marks such as seating marks could benefit examiners in their ability to understand how these are marks are produced, repeated, and withstand the firing process.

Second, it was revealed that material hardness of the bullet jacket and the cartridge case does not always promote one type of cartridge case composition to mark one component more frequently than another. For instance while over half of the data set in this study contained seating marks, all were not suitable for identification. In addition, previous research by Bennet (2007) indicated that the circumstances permitting comparison of seating marks were relative to the compositions of the cartridge case and bullets. However, this research revealed that some of the Wolf brand known match pairs contained little to no markings and the material hardness values for steel is much higher than brass, further indicating this as being a chance occurrence. Understanding what additional factors relate to the seating marks made by cartridge case mouths across multiple brands may provide a more effective depiction of these occurrences and assist examiners in determining what brands outside of those selected for this study exhibit seating marks suitable for comparison purposes.

The results of this study indicate that a more objective technological approach exists in the area of firearm and tool mark analysis which may eventually provide useful topographical information and statistical likelihoods that relate similarities across bullets when compared against one another. Surface analysis verification techniques have been demonstrated in previous research. A successful analysis of 13 test bullets, to include 3 deformed bullets was completed by Gardner (1979) and the results indicated that when striation information is extracted, computer techniques perform similar to examiners abilities through objective measures. Implications of this research specify that technology of this kind will assist in bridging the gap between subjectivity and provide improvements that assist law enforcement, improvements that derive more stringent Forensic science practices, and more appropriately, provide improvements that will enhance National security. This research further implies that utilizing this type of technology may provide an appropriate objective method for analyzing, visualizing, and reporting consistencies amongst seating mark or bullet surface topography identifications. In addition this research illuminates how this technology enhances striation position, spatial relationship, width, and depth as often viewed through the eye of the examiner, and as viewed in the provided photographs of captured known match pairs, may in the long run be quantifiable through the use of algorithms and advancements in future 3D technologies.

References

Association of Firearm and Toolmark Examiners. (2010). Association of Firearm and Toolmark Examiners. *AFTE Glossary 5th Edition* . AFTE.

Belveal, D. N. (1979). Firearms Identification Based Upon Bullet Comparisons: Expertise or Guess-Work. *AFTE* , *11* (2), 9-11.

Bennet, M. (2007). Bullet Identication to a Cartridge Case. *AFTE* , *39* (2), 148-150.

Berg, S. O. (1979). The Drama of Forensic Ballistics. *AFTE* , *11* (3), 44-46.

Budowle, B., Giusti, J. S., Baechtel, F. S., Fourney, R. M., Adams, D. E., Presley, L. A., et al. (1991). Fixed Bin Analysis for Statistical Evaluation of Continuous Distributions of Allelic Data from VNTR Loci, for Use in Forensic Comparisons. *American Journal of Human Genetics* , (48) 841-855.

Cantrell, D. (2010, June 8). *Barrels and Bullets: Conventional versus Polygonal Rifling*. Retrieved 07 26, 2010, from http://www.humanevents.com: http://www.humanevents.com/article.php?id=37197

Clow, C. M. (2008). A Method for the Production of Test Speciments for the Comparison of Bullet Seating Marks. *AFTE* , *40* (3), 296-299.

Doyle, J. S. (2010, July 6). *An Introduction to Forensic Firearm Identification*. Retrieved July 6, 2010, from Firearmsid.com: http://firearmsid.com/Bullets/bullet1.htm

Doyle, J. S. (2010, July 12). *firearmsid.com*. Retrieved July 12, 2010, from www.firearmsid.com: http://firearmsid.com/A_bulletIDrifling.htm

Goddard, M. C. (1987). The Identification of Projectiles in Criminal Cases. *AFTE Journal* , *19* (4), 393-399.

Hall, A. L. (1931). The Missile and the Weapon. *The American Journal of Police Science , 2* (4), 311-321.

Hamby, J. E. (1973). Proved Guilty by Ballistics (Hadley vs. Arizona). *AFTE , 5* (6), 5-9.

Heard, B. (2008). *Handbook of Firearms and BallisticsL Examining and Interpreting Forensic Evidence.* Chichester, West Sussex: Wiley-Blackwell.

Lambert, R. R. (1971). Firearms Identification. *AFTE Newsletter , 14*, 23-29.

Leeds Forensic Systems. (2010). Retrieved 7 26, 2010, from www.leedsforensics.com: http://www.leedsforensics.com/sitemap-firearms.asp

Levine, R. T., & Kuehner, M. N. (1998). Bullet to Cartridge Case Comparisons. *AFTE , 30* (2), 318-319.

Locke, R. L. (2005). A Study of Cartridge Case Impressions on Bullets. *AFTE , 37* (3), 187-193.

Material Hardness. (2001). Retrieved 07 27, 2010, from www.calce.umd.edu: http://www.calce.umd.edu/general/Facilities/Hardness_ad_.htm

Murdock, J. E. (1981). The Survival of Identifiable Bullet Striae Caused by Defects in the Forward Rim of a Revolver Chamber. *AFTE , 13* (3), 62-71.

National Research Council (2009). *Strengthening Forensic Science in the United States: A Path Forward.* Washington D.C.: National Academies Press.

National Institute of Justice. (2004). Education and Training in Forensic Sicence: A Guide for Forensic Science Laboratories, Educational Institutions, and Students. Washington D.C.: National Institute of Justice.

Police Equipment Reviews. (2010, 7 26). Retrieved 7 26, 2010, from www.policeequipmentreviews.com: http://www.policeequipmentreviews.com/articles11.html

Police Link. (2010). Retrieved 7 30, 2010, from Policelink.monster.com: http://policelink.monster.com/products/products/945-beretta-96-brigadier

Prieto, M. A. (1982). Firearms Identification Lessons. *AFTE , 14* (3), 45-96.

Rathman, W. (1975). Training for Firearms Examiner. *AFTE Journal , 7* (1), 14.

Thornton, J. I. (1979). The Validity of Firearms Evidence. *AFTE Journal , 11* (2), 16-18.

Welch, N. E. (1981). Matching A Bullet To A Cartridge Case. *AFTE , 13* (4), 79-83.

White, V. (2005, July 26). Process Engineer for Centerfire Ammunition at Remington Arms Ammunition Plant. (D. Christophe, Interviewer) Lonoke, Arkansas.