FORENSIC FIREARMS EXAMINATION

A Thesis submitted for the

Degree of Doctor of Philosophy

Of the University of Strathclyde

By

JAMES EDWARD HAMBY

A.A., B.S., B.S., M.A.

FORENSIC SCIENCE UNIT

Department of Pure and Applied Chemistry

University of Strathclyde

Glasgow G1 1XW

Scotland, U.K.

2001

University of Strathclyde Glasgow

<u>The following pages have been redacted for copyright reasons</u>

<u>Appendix 1 :</u> AFTE Journal (volume 31, Number 3). Summer 1999 p.266-283. 30th Anniversary Edition The history of Firearm and toolmark identification by James E. Hanby and James W. Thorpe

Appendix 2 : J Forensic Science 1997, 42(3): 461-465. Firearms reference collections – Their size, composition and use Hanby . J. E., Thorpe, J. W.

Appendix 3 : AFTE Journal (volume 31, Number 3) Summer 1999. p.291-297. 30th Anniversary Edition. A historic perspective of Firearms Reference Collections: Their Size, Composition and Uses

COPYRIGHT

Acknowledgements

I would like to express my deep appreciation to my advisor, Dr. James W. Thorpe, for his guidance and friendship over the past several years. Thanks are also in order to Dorothy Thorpe for making me feel at 'home' during my many trips to Scotland.

I also extend my appreciation to the entire staff of the Forensic Science Unit at the University of Strathclyde. Thanks are also due to Drs. Bob Briner and Mike Cole for their assistance as members of my oral defence committee.

My sincere appreciation and admiration to the men and women of the Association of Firearm and Toolmark Examiners (AFTE), for their dedication in serving our profession. A large debt of gratitude is owed those who have gone before us.

I also wish to thank the many individuals that have helped guide me during my lifetime, especially during the 30+ years that I have actively been involved in forensic science – each of you know who you are!

To the entire staff of the Indianapolis – Marion County Forensic Services Agency for their friendship and support during my tenure as Director of the Agency. A special thanks to John Mann, Dave Brundage and Mickey French for their assistance.

Finally, to my wife Patricia for her encouragement and support during this rather lengthy process.

Abstract

The history of forensic firearms examination was evaluated to determine how the field has developed during the past 200 years; especially within the past 100 years. As a result of this evaluation, some related issues were identified for study. The economic and general uses of firearms reference collections were considered as the collections represent potential security considerations within forensic laboratories. A survey was conducted to determine how firearms examiners used their collections, as well as their receptivity to augmenting the collections with modern technology such as photographs and CD-ROM's. A world-wide survey resulted in responses from 110 forensic laboratories. Examiners stated that the collections were used for training, repairing damaged evidence firearms, and demonstration purposes, and whilst they were prepared to accept modern technology to augment their collection, stated that such augmentation could not replace the actual collection. Research was conducted to partially answer some legal issues, such as Daubert, et al., by test firing bullets from consecutively rifled barrels to obtain best known 'match' and 'non-match' bullets. To date, some 201 examiners from several countries have evaluated the bullet test sets with no errors. Further research was conducted by test firing four cartridges from 617 similar 9mm Glock pistols and microscopically evaluating the fired cartridge casings to determine if they were identifiable to themselves and not the other casings. All of the casings were identifiable to themselves and not to the other 616 casings. Advances in technology have allowed the development of automated ballistics imaging systems. Research, using the previously cited test bullets and cartridge casings, was conducted to evaluate the capability of the various systems, in conjunction with the abilities of firearms examiners. Three different automated systems were used to evaluate the

bullets from the 10-barrel test with excellent results. One automated system was used to evaluate the 617 cartridge casings, again with excellent results.

Table of Contents

INTRODUCTION TO FIREARMS AND TOOLMARK IDENTIFICATION

INTRODUCTION

Firearms identification is currently accepted as an integral part of most forensic science[1] laboratories. The history of the forensic science of firearm and toolmark identification, often referred to a 'forensic ballistics', has evolved over the past 200+ years and is interesting to many forensic scientists as well as others within the academic, judicial and legal community. It should be noted that while the use of the term 'firearms identification' is the most popular term used, both within and without the laboratory, firearms identification is actually a specialised area of toolmark analysis.

In many laboratories, the firearms section may be responsible for the examination of wide variety of related evidence. These examinations include:

Examination of submitted firearms to determine the manufacturer, model, calibre, serial number and functionality.

Examination of evidence bullets and cartridge casings, in conjunction with a submitted evidence firearm, to determine if either, or both, were fired in or from the firearm.

Evaluation of evidence ammunition to determine the manufacturer, calibre, bullet type and country of origin.

Examination of submitted tools in conjunction with evidence toolmarks or silicone casts to determine if the tool was used to create the toolmark. Restoration of altered, modified, or obliterated serial numbers on a wide variety of numbered items.[2]

Analysis of gunpowder patterns on a variety of submitted evidence, which may include a biological matrix such as flesh or hair, clothing, glass, et al., in conjunction with submitted firearms and ammunition components, to determine the distance between the firearm muzzle and the point of impact.

Examination of submitted evidence to determine if the various items were, at one time, a single item – often referred to as physical matching.

Examination of footwear and tire evidence, in conjunction with recovered impression evidence from the crime scene, to determine if the evidence patterns have a common origin with the submitted footwear or tires.

Shooting scene reconstruction using trajectory analysis to determine the sequence of two or more events in a particular incident utilising information derived from the physical evidence.

Analysis of gunshot residue (GSR) using various instrumental and chemical techniques to determine if an individual has either fired a firearm or has been in close proximity when the firearm was discharged. In the majority of laboratories this type of analysis is usually assigned to the chemistry section.

Receive evidence firearms into the laboratory and test fire two cartridges for entry into the National Integrated Ballistics Identification Network (NIBIN) (United States) or a similar type system elsewhere for comparison against firearms evidence from laboratories within the NIBIN network.

Other duties as appropriate, which may include preparation of the examiners conclusions in a written laboratory report, conducting training for various law enforcement and judicial groups, Judges, Attorney's, and presentation of his or her findings before courts of law.

In 1876, a Georgia State (USA) Court allowed a witness, who was experienced in the use of firearms, to provide expert testimony concerning the amount of time that had elapsed since a gun was last fired. This type of examination was possible in firearms using black powder propellant, as the residues from this type of powder produce type of fouling that changes with time. Another case occurred in a Texas State (USA) Court in 1883. The court allowed an individual to provide expert testimony on the elapsed time since the evidence firearm was last fired; his testimony was based on his examination of the fired paper patch, the percussion cap and the fouling within the barrel of the firearm. These two cases, which involved black powder firearms, represent a type of examination that has become obsolete.

Examination of fired cartridge components

Firearms and toolmark identification[3] has evolved over a period of 200+ years. The earliest case involving a firearms identification occurred in 1794[4] in Lancashire, England. An individual was shot in the head and during the autopsy a piece of paper, the patch used to provide a seal between the ball and gunpowder, was found in the wound. A suspect was arrested and found to be in possession of a similar piece of paper. A subsequent comparison of the two pieces of paper showed that the two pieces had once been one, which resulted in a death sentence for the accused.

In 1835, in the City of London, England, a servant reported that someone had attempted to rob him and had then fired a shot into the house. A Bow Street Runner called Henry Goddard, no relation to Calvin Goddard of later firearms identification fame, investigated the case. Goddard was able to identify the mould mark, actually the sprue cutter mark, used to manufacture lead balls from molten lead on the fired ball. He also examined the paper patch and was able to identify it as having been torn from a newspaper that was found in the room of the servant. Goddard's careful observations and subsequent examination of the physical evidence from the crime scene were instrumental in bringing the guilty party to justice. It appears that the servant was trying to gain favour with his employer by staging a robbery in hopes of his receiving a reward. Although paper patches are seldom used in black powder firearms today, the physical comparison of evidence such as the pieces of paper is widely used in laboratories. Additionally the use of plastic wads, which have superseded patches, in shotshells may allow the identification of the wad to the shotgun.

Some of the earliest recorded cases involving simple firearms identification using the class characteristics of the projectiles occurred during the United States Civil War. In 1863 Confederate General Stonewall Jackson was shot and fatally wounded on the battlefield. When the bullet was removed from his body an examination identified it as a 67 calibre ball projectile typical of those used by his own forces such as Hill's

Division. It was also known that the Union forces, the opposing force, used the 58 calibre minie ball projectile so that Jackson could only have been shot by one of his own men. A year later, in 1864, Union General John Sedgwick, was killed by a Confederate sniper from a reported distance of 800 yards. When the bullet was removed from his body, it was determined that the calibre, the hexagonal shape of the bullet and the type of rifling were consistent with the Whitworth rifles imported from England by the Confederate forces for sniping purposes. These two cases[5] show that in the early days differentiation between firearms was based solely upon what are now termed "class characteristics" namely the calibre and shape of the bullet.

Though some firearms have been rifled since 1500[6] it was not recognised until the late 19th century that the rifling was of value for identifying a fired projectile to the firearm. A Minnesota State (USA) Court, in 1879, used the services of a qualified gunsmith to examine a fatal bullet in conjunction with two suspect revolvers.[7] His examination of the two revolvers revealed that one of the revolvers had actual rifling marks while the other revolver only had false rifling marks at the muzzle. The examination of the marks on the fatal bullet allowed the gunsmith to testify that the bullet could not have been fired from the revolver with rifling but could have been fired from the other revolver.

In 1889, Professor Alexandre Lacassagne of Lyon, France, published a paper titled "La Deformation Des Balles de Revolver" (Deformation of Revolver Bullets) in Criminelle et Des Sciences Penales.[8] In a particular case, he microscopically examined a bullet that had been removed from the victim of a shooting and observed that it contained seven grooves. A revolver was located under the floorboards of the suspect's room and when it was examined, it was determined to be of the same calibre as the murder bullet and it also had seven grooves. The suspect was convicted of murder. This was the first time that a microscope was used to examine fired cartridge components. Until the close of the 19th century the examination of fired projectiles was fragmentary, but in 1900, the first steps were taken to make this examination systematic. An article published that year[9] dealt with a variety of issues including how to measure land and groove markings, impressions on the bearing surface of the bullet caused by the rifling process. It discussed the examination of gunpowder residues in barrels of firearms and the changes that take place over time after the weapon is fired. This performed a valuable service as it alerted others to the potential for evaluating markings found on fired bullets. Two years later, in 1902, a Massachusetts State (USA) Court allowed an individual to provide expert testimony on the effects of rifling and other markings in a gun barrel upon bullets fired through the barrel.

In 1912, Robert Churchill, a famous English gun maker and early firearms examiner was contacted by the local police department for assistance with a case involving the use of firearms.[10] A local police Inspector was shot and killed by a suspect attempting to avoid arrest. An investigation revealed both a suspect and a firearm, which had been disassembled before being buried. Churchill was able to reassemble and test-fire the firearm and conduct an examination of the bullets from the firearm and the victim. In his conclusions Churchill stated: "When I had compared the test bullets with the murder bullet, I was satisfied that not only was the bullet of exactly the same calibre as the suspect revolver but it also bore exactly the same number of grooves, similar in width and rifling angle as the test bullets. I explained to the inspector that different firearms manufacturers rifle their weapons with a wide variation in the number, width, depth, angle and grooves". Churchill testified in court, using numerous photographs to demonstrate his results and the suspect was found guilty. Although not specifically discussed by Churchill, his description leads one to believe that his identification was based on class and not individual characteristics.

A significant milestone in firearms identification history occurred when Professor V. Balthazard devised a series of procedures to identify fired bullets to the firearms from which they were fired.[11] He achieved this by taking an elaborate series of photographs of test fired bullets from the firearm as well as evidence bullets. The photographs included the rifled areas of each land and groove impression and were carefully enlarged to allow the observed markings to be compared by Balthazard and his staff. He applied these same specialised photographic techniques to the examination and identification of cartridge casings using firing pin, breech face, ejector and extractor marks. His work is very important as it represents the actual evaluation and identification of the individual characteristics of the fired bullets.

In April 1925, the Bureau of Forensic Ballistics, a private firearms identification laboratory, was organised in the United States by Calvin Goddard, and others. Gravelle, one of the staff at the Bureau, adapted a comparison microscope for use in the examination of fired bullets and cartridge cases; providing the necessary tool to evaluate fired cartridge components. Utilisation of the microscope replaced the more cumbersome photographic methods previously employed, a major step forward in firearms identification. The Bureau also acquired a large collection of reference standards[12] that included firearms[13] and ammunition components.

In 1907, several soldiers from a nearby US Army Infantry Regiment were allegedly involved in a riot in the small Texas town of Brownsville. During the hours of darkness, and during a ten-minute period, the soldiers were alleged to have fired some 150 to 200 shots from their rifles throughout the entire town. The facts surrounding the 'riot' are very much in question and although the case was supposedly investigated, it was never determined if any soldier actually participated in the riot. Following the alleged riot, townspeople 'found' in a back alley of the town a total of 39 fired 30-caliber cartridge cases and some fired bullets. These items, and numerous rifles belonging to three infantry companies, were collected and sent to the staff of Frankfort Arsenal for their examination. The arsenal staff studied the submitted evidence and then devised a method of identifying fired cartridge casings to rifles. The arsenal staff was able to specifically identify 33 of the fired cartridge casings as having been fired from four of the submitted rifles.[14] This exhaustive examination of evidence, and subsequent written report, is the first recorded instance in the United States of fired cartridge casings being evaluated as evidence.

Whilst others continued to examine and identify fired cartridge casings over the next several years, it was not until 1927 that a further extensive study confirmed that it was possible to identify a cartridge case to the firearm in which it had been fired. A police constable was shot and killed in Epping Forest, England, and a fired cartridge case recovered at the scene. The police consulted with a private examiner, Robert Churchill, who, in conjunction with ordnance officers at Woolwich Arsenal, test fired over 1,300 revolvers similar to the suspected murder weapon. He demonstrated to the court that the breechface markings on the evidence casing were individual to the suspect revolver.[15]

There are a considerable number of shooting incidents when, at the early stages of the investigation, only fired cartridge components are available for examination; a suspect weapon may or may not become available at a later stage. Early practitioners used their reference materials, such as ammunition that they collected, to aid in the investigation of items submitted for their evaluation and enabled them to identify possible makes and types of ammunition that may have been used in the incident. Additionally, a fired component could be examined and the class characteristics of the firearm used to identify the makes and models of firearms that may have fired the component. Such information can assist the police during their investigations by providing crime intelligence. These reference materials, for all practical purposes, became physical databases.

During the earlier years, the databases that were accumulated were as the direct result of the individual firearms examiner who decided to collect various items for use in his own laboratory. Other individuals both collected data and provided the information for others to use; most notably Dr. J. H. Mathews. He published a two-volume set of books[16] which contained extensive reference materials; Volume I described laboratory techniques for examining firearms, and most importantly rifling data on a wide variety of handguns and photographs of the firing pin impressions on rimfire cartridges. Volume II contained several hundred photographs of handguns to assist in their identification, and photographs of identifying marks. Volume III,[17] published in 1973, contained additional data on rifling characteristics, several hundred original photographs and illustrations of firearms, and other reference material.

These databases, both physical and paper, were so useful that a governmental organisation, the Federal Bureau of Investigation (FBI), decided to resource a large-scale database of general rifling characteristics; the GRC file. At the time of inception, the file provided the characteristic measurements from some 18,000 rifled firearms. The measurements include the number of lands and grooves, direction of twist, and measurement of land impressions. The GRC file[18] has been found to be a very useful tool and is now available in computer format for use within forensic laboratories.

Computers have continued to impact forensic firearms examination. Whilst in the past, examiners have had to rely on the comparison microscope and their particular abilities, recent innovations in digitising and evaluating fired component items using algorithms, has greatly benefited the firearms examiner. Computers have also provided better crime intelligence by allowing access not only to the individual's laboratory database but also to those of all laboratories involved in the wide-area network. This is discussed in more detail in Chapter 5.

Range of fire and wounding

In 1852, a sheriff was asked to determine whether the hole in a homicide victim's shirt was a bullet hole or a tear. The sheriff, using the suspect firearm and victim's shirt, conducted experiments by test firing the weapon into the shirt. The sheriff testified in court that the hole in the shirt was from a gunshot and not a tear and the suspect was hanged for murder. This case makes one wonder why an autopsy did not show the presence of a bullet, or at least a bullet wound. It represents another aspect of firearms examination and one which is closely linked to the medical profession. It also represents an early case, involving the use of the evidence firearm and clothing, to conduct an experiment to reach a conclusion. This illustrates the need to establish the circumstances of shootings involving injury, investigations that today are carried out jointly by medical and forensic science personnel.

In Paris, France in 1857, a Monsieur Noilles published a thesis titled 'Les Plaies Par Armes a Feu Courtes'. This dealt with the subject of wounds made by small firearms and was one of the early papers that dealt with this subject. In 1885, in Lyon, France, a study titled "Etudes Medico-Legales des Plaies d'Entrëe Par Coups de Revolver" (Medico-Legal Study of Wounds of Entry Wounds Caused by Revolver Bullets) was published by the Poix. Travail du Laboratorie du Medicine-Legale de Lyon. These are some of the first recorded studies that involved the examination and reporting on wounds caused by revolver bullets and represented information of value to both the medical field and the field of forensic firearms identification.

One of the first recorded instances of someone being permitted to provide testimony to the effects of firing a pistol at human hair and a paper target occurred in a Kansas State (USA) Court in 1896. The court permitted the witness, experienced in the use of firearms, to conduct various experiments using the evidence pistol and similar cartridges in an attempt to determine the effect on firing at hair and targets at close distances. The witness was then allowed to provide testimony as to the results. In 1898, this type of analysis was further expanded when in Paris, France, a Mr. Corin published an article titled "La Determination de La Distance a'Laguelle un Coup de

Feu a e'te' Tire" (Determination of the distance at which a shot has been discharged from a firearm). These two reports are examples of early distance determination experimentation, which has continued to date.[19,20,21,22,23]

Mrs. Camille Holland was shot and killed in Essex, England in 1899. Her body was recovered in 1903 and it was determined that she had been shot with a 32 calibre revolver. E. J. Churchill, using a similar revolver and ammunition, fired test shots into sheep's skulls at varying distances. He examined the skull of the victim in conjunction with the damage observed in the sheep's skulls and provided testimony in court that, in his opinion, the fatal shot was fired from a revolver at between 6 and 12 inches. The accused was convicted and hanged.[24] This case is interesting as it shows the progression of determining the range of fire, in that it involved the evaluation of damage to a part of the body as opposed to earlier cases involving merely scorching of clothing and hair.

A court case in a Wisconsin State (USA) Court in 1908 involved experimentation leading to expert testimony. The issue in question was the distance between a target and a gun when it was fired. The trial judge allowed an individual to provide expert testimony on his observation of the presence and/or absence of gunpowder at various distances and represents another early case involving distance determination evaluation.

System development

Although the courts had been using expert testimony relating to firearms examination for many years this testimony had been provided by private individuals who for whom forensic investigation was a very minor part of their duties. However events in 1929 were to precipitate the establishment of a properly organised and funded professional forensic science service which included firearms examination.

In Chicago in 1929 a rival gang shot seven men to death; an event that outraged the public who demanded a thorough investigation.[25] The grand jury foreman engaged the services of Calvin H. Goddard of the Bureau of Forensic Ballistics to examine and report on the firearms related evidence. Goddard's careful and concise examination of all the firearms related evidence was significant. Goddard was able to conclusively state that the killers had used one 12-gauge (12-bore) shotgun and two Thompson submachine guns. He noted that one of the Thompson's submachine guns was fired using a 50-round drum magazine while the other was fired using a 20-round box magazine. He subsequently identified weapons that were obtained during the search of a suspect's home as being the firearms used in the shooting. As no public funds were available for a laboratory, the jury foreman and others, said that they would provide the funding to create a full service crime laboratory and hired Goddard as the director. Goddard accepted the position and became the Director of the Scientific Crime Detection Laboratory (SCDL) the first full service laboratory in the United States.

The growing status and complexity of firearms investigation resulted in a number of textbooks being written. The knowledge acquired by an individual would no longer vanish at his retirement but would be available to others. In 1934, Major Sir Gerald Burrard wrote a textbook[26] titled "The Identification of Firearms and Forensic Ballistics" that was published in London, England. In it Burrard discusses many of the early cases that occurred throughout the British Empire to include those of pioneer firearms examiners. Two textbooks closely followed this on firearms identification published in 1935. [27,28] These three textbooks sufficed until the late 1950's, as there was a lack of evolution in the field. Jury and Weller revised the text by Hatcher in 1957 and Davis published his book on the Striagraph in 1958. Interestingly, the next textbooks in the field of firearms examination and identification didn't appear until 1996 and 1997.[29,30]

Whilst it would appear that the field of firearms identification had stagnated, especially when one considers that there was a gap of some 38 years between textbooks, nothing could be further from the truth. In the period from 1948, the foundations of a professional organisation for firearms examiners were being laid

In 1948, the First American Medicolegal Congress' was held in St. Louis, Missouri. This meeting, a subsequent meeting later in the same year, and several committee meetings during 1949, was the genesis for the American Academy of Forensic Sciences (AAFS) to be organised and named in 1950. Two of the papers presented at the initial meeting concerned firearms identification. Over a period of several years, participants at the meetings, especially firearms examiner practitioners and those interested in the field, would meet in the evenings and discuss their cases with one another. These informal meetings became the genesis for the Association of Firearm and Toolmark Examiners (AFTE) to be formed in 1969 - 21 years after the initial AAFS meeting in 1948.

In 1969, in recognition of the potential requirement for an association dealing specifically with the identification of firearms and toolmarks, thirty-five police and civilian specialists from throughout the United States and Canada gathered at the Chicago Police Department Crime Laboratory to discuss formation of an association. The purpose of the meeting was described in the program: "this meeting is being held to determine the advisability of forming an organisation of Firearms and Tool Mark Examiners. It is hoped that the organisation will consider future meetings that could be devoted to the presentation of scientific and technical papers, descriptions of new techniques and procedures, review of instrumentation and the solution of common problems encountered in these scientific fields".[31] The organisation was established and called the Association of Firearm and Toolmark Examiners (AFTE). Today, the association has in excess of 850 members from some 29 countries.

In 1969, the association started publishing what has now become the AFTE Journal. This provides a conduit for disseminating information to the members covering research, case studies and technical information. In 1970, and each subsequent year to date, the Association of Firearm and Toolmark Examiners (AFTE) has hosted an Annual Training Seminar at a location throughout the United States and Canada. The primary purpose of the annual training seminars is to provide for the interchange of information as it relates to all aspects of the science of firearms and toolmark identification.

In addition to scientific and technical issues the association has been concerned to raise the status of the profession. It established a code of conduct, which was binding on its members in the late 1970's. To supplement its training activities it first published a training manual in 1982 and in 1998 began to monitor the competence of its members by means of an examination certification program.

The success of the association is illustrated by it being approached to provide experts to investigate firearms aspects of a number of controversial high profile cases. In 1975, due to continuing controversy surrounding the killing of Senator Kennedy, a petition was made to the Superior Court of California, County of Los Angeles. The petition requested that the firearms evidence be re-examined due to the continuing controversy, much of which was generated by several self styled 'experts'. The court granted the petition and ordered that a panel be formed to conduct the re-examination. The American Academy of Forensic Sciences (AAFS) and the Association of Firearm and Toolmark Examiners (AFTE) were contacted and requested to submit names of firearms examiners to the Attorney General of the State of California. The Presiding Judge convened a seven-member panel that included six AFTE members.[32]

In 1989, a serious misidentification occurred in the LAPD Firearms Identification Unit. The unit had misidentified a firearm in a homicide investigation and the suspect arrested. His attorney submitted the evidence to a private laboratory where the examiner reported that the weapon was not the one that had been used. This controversy resulted in LAPD requesting the services of four AFTE members to inspect the evidence, and evaluate the firearms unit as well. The team evaluated the firearms evidence and discovered that a misidentification had been made. Additionally, an evaluation of the unit revealed serious shortcomings in the overall operation and a number of recommendations made as how to correct them.[33]

In 1986, the FBI's Forensic Science Research & Training Centre (FSRTC), at

Quantico, Virginia (the FSRTC is part of the FBI Laboratory Division) announced the creation of a training course for firearms examiners. The course, titled "Specialised Techniques in Firearms Identification", was designed for court qualified examiners and covers a variety of subject matter designed to enhance the level of proficiency for examiners.

In 1990, the International Wound Ballistics Association (IWBA) was organised in California (USA). The formation documents stated the following "It (IWBA) is comprised of scientists, physicians, criminalists, law enforcement members, engineers, researchers, and others engaged or interested in the study of wound ballistics". Many AFTE members belong to IWBA, and the official publication of the association, Wound Ballistics Review, disseminates a wide variety of information relating to wound ballistics.

Legal issues

As earlier described the courts for many years, readily accepted testimony relating to firearms related evidence. Since 1993, the United States Supreme Court has provided a series of legal rulings that have changed the legal standard for those individuals that provide scientific testimony. This includes expert testimony for firearms and toolmark identification, in US Federal Courts as well as some state courts. One of the new standards, referred to in the United States as the 'Daubert' ruling, has required trial judges to be the 'gatekeepers' of expert evidence in deciding whether or not it is admissible. The 'Daubert' ruling, and other subsequent rulings by the court, have established four criteria by which scientific testimony must be evaluated before it can be admitted. The abbreviated criteria are as follows:

1. Testability – can the scientific principle be tested?

2. Known or potential error rate – can the potential error rate be quantified?

3. Peer review and publication – has the concept or technique been scrutinised by others knowledgeable in the field?

4. General acceptance of the relevant scientific community – is the concept or technique held in sufficient regard to be widely adopted?

This ruling has generated an appreciable amount of discussion within the firearms examination community. One method of meeting some elements of the above criteria is to conduct scientific research, and then publish the results in peer-reviewed journals such as the AFTE Journal, the Journal of Forensic Science (AAFS), or the Journal of the Forensic Science Society (Science and Justice).

In 1998, several articles[34,35,36,37] were published that were the results of research concerning both criteria for identification studies and striae reproducibility on a firearms barrel. These articles are part of an ongoing process by members of AFTE, and other forensic scientists, to fully articulate the science behind the field of firearm and toolmark identification. The studies, and others not mentioned, include a substantial amount of research by numerous firearms examiners to evaluate the number of striae on firearm and toolmark impression evidence using a 'line-counting' process sometimes referred to evaluating 'consecutive matching striation'.[38] Other studies involve the process of sending various examiners unknown, or blind, test samples to ascertain if they can successfully identify which bullets were fired from various barrels. Additional studies involve the use of current (and proposed) computer based technologies such as Drugfire, IBIS, and SciClops in determining their ability to assist the examiner in correctly identifying impression evidence.

CONCLUSIONS

In the early part of the last century (1900 — 1930), the science of firearm and toolmark identification was recognised by numerous judicial systems in several countries around the world. Legal recognition was due, in part, to the efforts of several individuals from various countries that had conducted research and experiments into the identification of fired projectiles and cartridges cases to the specific firearms.

In the middle part of last century (1930 — 1970), the science of firearm and toolmark identification continued to evolve. For example, in the United States, the Scientific Crime Detection Laboratory (SCDL) began operations and was followed by formation of the Federal Bureau of Identification (FBI) Laboratory. Additionally, many other countries also recognised the requirement to provide this type of forensic analysis and established firearm and toolmark sections either in existing laboratories or as new laboratories. The misuse of firearms in criminal cases, especially in the United States, greatly increased in the 1960's.[39] In recognition of the need to exchange information and promote continuing scientific research and professional standards in the field of firearm and toolmark identification, thirty-six individuals met in Chicago, Illinois in

February 1969, and organised the Association of Firearm and Toolmark Examiners (AFTE).

In the last part of the last century (1970 — 2000), the science of firearms and toolmark identification has continued to evolve. The science has greatly benefited from the numerous technological advances that have occurred during this time period. These advances include innovations in one of the primary tools of the firearm and toolmark examiner — the binocular comparison microscopes. Many of the current comparison microscopes have been equipped with photomicrography and closed circuit television (CCT) units, which allow for direct viewing or instant digital documentation.

The ongoing development of computers has provided the firearms examiner with such useful equipment as Drugfire and IBIS (NIBIN) Systems. Using advanced computer technology, these two systems allow for the capturing of digital images of fired bullets and cartridge casings which are then analysed to provide the examiner with a list of possible 'hits' for his or her examination using a optical comparison microscope. This provides the examiner with the opportunity to search for possible identifications on fired evidence bullets and cartridge cases in the laboratory as well as at other laboratories that are connected on the system. A more complete discussion of automated systems and others will be discussed elsewhere in this thesis.

During this same time period, several court decisions in the United States, such as Daubert and Staryzepel have caused a deal of concern for laboratory scientists that deal in the analysis and evaluation of impression type evidence. These types of examinations and identifications, specifically in the forensic science fields of firearms & toolmark identification, latent print identification, and questioned documents identification often rely on subjective as well as objective criteria.

Another substantial issue, for firearms examiners, that has surfaced in several laboratories during the past several years is the economics, security issues, and time constraints related to maintaining weapons reference collections in the laboratory. Even the uses of digital imaging units provide significant issues that examiners must address in their laboratories.

Daubert and subsequent related rulings caused the major legal problems for firearms examiners. It is alleged that the current subjective examination procedures cannot assign a bullet as having been fired by a particular gun. It is always possible that another, unidentified gun will form markings indistinguishable from the gun in question. A number of trials have been carried out which were intended to justify this argument but all so far have weaknesses. In some instances the examiners knew the answer before carrying out the work so that the findings are biased. In other instances, it is argued that the firearms used in the trials do not represent the closest known 'non-match' or the trials are too limited in scope. The legal profession can supply endless criticism.

Perhaps the best designed trial is that of Brundage who ensured that he had the closest possible known 'non-match' gun barrels by obtaining consecutively rifled barrels from the manufacturer. Not only did he obtain them he ensured that they were consecutively rifled by physically observing their manufacture. He then made sure that the trial was truly "blind" by sending the bullets to examiners in other laboratories. However this test is open to the criticism that the results were not objectively evaluated and that the trial was carried out on too small a scale. In addition there was no attempt to calculate an error rate.

The rise in firearms related crimes and population mobility are such that there is a desperate need for an analytical system with a high sample throughput and covering an extensive area. Modern computerised firearms examination systems, and those being developed, can meet these needs. However to be of value their results must be demonstrably reliable. While they have been extensively tested they have not been assessed to the same standard as some human examiners. This is the ability of the human examiner to distinguish between bullets fired from consecutively rifled barrels; the closest known non-match.

Additionally automated systems are not cheap to purchase or operate and do they have advantages over the human operator? Economics and modern technology are beginning to affect firearms examiners in one other way. Virtually all laboratories have a reference collection of firearms and of ammunition. Such collections are expensive to establish and to maintain. A lot of relevant information is available in databases; are the reference collections still necessary?

WEAPONS REFERENCE COLLECTIONS

INTRODUCTION

Today there is major public concern in many countries, including the United States of America, about the possession of firearms. The majority of forensic science laboratories in the United States possess a firearms reference collection and these collections may come under scrutiny from the public, administrators or laboratory managers. Objections to such collections can include the cost of collecting, the cost of space for storage, and security for the collection. This is especially so since firearms are bulky, are a potential target for criminals and modern technology may be held to make such collections redundant.

Historically, little information has been published in the forensic science literature concerning the acquisition, composition or uses of the Firearms Reference Collection (FRC) or the Firearms Reference Library (FRL) in forensic laboratories throughout the world. The requirement for operational forensic science (crime) laboratories to obtain and maintain firearms for the laboratories' Firearms Reference Collection or Library has been partially documented in numerous articles, books and monographs by many individuals including those who were early pioneers in the field of firearms identification. These individuals include Colonel Calvin H. Goddard, Major General Julian S. Hatcher, Lieutenant Colonel Jack Gunther and Professor Charles Gunther, Major Sir Gerald Burrard, Robert Churchill, John E. Davis, Sir Sydney Smith, Professor J. Howard Mathews, and Professor Paul Kirk.

Although many of these individuals wrote extensively on the subject of firearms identification (forensic ballistics), very few felt the need to specifically document the number and types of firearms that they felt should be in a 'firearms collection'. Neither did these individuals fully discuss their reasons for the acquisition, use, or maintenance of their reference libraries. In the majority of their writings on the subject of collections, most simply stated that they had a number of firearms available to them for their work in firearms identification.

One can assume from a study of the literature that the early practitioners of the science of firearms identification didn't feel the need to elaborate on the requirement for a reference collection. This assumption is explainable inasmuch as the early pioneer examiners, many of whom were engineers, medical doctors, senior Army officers, etc., were by nature, inquisitive and science oriented, and understood the absolute requirement for having proper 'standards' available to them for their work. These individuals probably didn't feel it necessary to document weapons collections as the field was in its infancy and the individuals who were practising examiners (Churchill, Burrard, Smith, Goddard, Crossman, et al) recognised the importance of maintaining firearms and maintained their own extensive collections. While it is recognised that some other countries may have established governmental forensic laboratories that conducted firearms identification examinations, it would appear that the majority of those initially involved with providing these services were private citizens. These individuals worked firearms identification cases for various governmental agencies on request and include Churchill, Burrard, Smith and Pollard in the United Kingdom along with Goddard, Waite, Crossman and several others in the United States.

To better understand how the requirement for firearms reference collections began, it is necessary to know how forensic laboratories evolved. In the United States and other countries, for example, many larger police agencies started their own firearms identification units in the late 1920's and 1930's. Several police departments in the United States organised firearms identification units in the early to mid-1930 as a result of several publicised events involving the use of firearms. Although there are several crimes that involved firearms identification in the early 1900's, there are two that received a great deal of attention from the print media in the United States. These are the double murder by Sacco - Vanzetti that occurred in South Braintree, Massachusetts on April 15, 1920, and the St. Valentine's Day Massacre, when seven individuals were murdered, that occurred in Chicago, Illinois on February 14 1929. These two events, and several other less publicised criminal events, greatly hastened the establishment of firearms identification units in the United States. At the same time, similar misuse of firearms in the commission of crimes in the British Empire hastened the advent of individuals performing similar types of examinations for governmental agencies. Three early British pioneers were Robert Churchill, Sydney Smith and Hugh Pollard.

Subsequent to the Sacco-Vanzetti and St Valentine's Day events in the United States, and due to the ever increasing misuse of firearms in criminal matters, the Chief of Police or Sheriff (senior law enforcement officials), began to organise firearms identification units in their departments. The Chief (Sheriff) would select an individual from his department - who was familiar with firearms, such as range masters, target shooters, or a member of the department armoury, and give them the mission of organising the firearms identification section. In some instances, the only instructions provided to the new firearms examiner was to "start doing firearms (ballistics) examinations", while the equipment provided was limited to a basic comparison microscope and a few books. The examiner was expected to use his skills and talents to organise the newly created unit.

Colonel Calvin Goddard, previously mentioned and considered by many examiners in the United States to be the 'father' of firearms identification, provides an excellent review of the history of firearms identification in an article that he wrote for the Chicago Police Journal.[40] Goddard later wrote, that Charles E. Waite, (later Judge Waite) started a collection of firearms in 1915 for his firearms identification efforts that included "a collection of several hundred revolvers, single shot pistols, repeating and automatic pistols of all makes, calibre and patterns, from every part of the globe".[41]

Many of these early examiners enjoyed the opportunity to develop this new science for their departments and used considerable initiative to obtain adequate space, tools, books, and firearms and ammunition for their reference collections. Often, the newly appointed firearms examiner would simply obtain firearms and ammunition from his associates in the police department's property room or from local courts after criminal charges were adjudicated. For example, Captain William Proctor, Chief of the Massachusetts State Police - and one of the prosecution's firearms experts in the Sacco-Vanzetti case - had begun his reference collections in the late 1910's by "confiscating all bullets, cases, cartridges, and weapons that came the way of the

Massachusetts State Police".

Robert Churchill, a famous English gun maker and early pioneer firearms examiner, first provided testimony as an examiner in the United Kingdom in 1911. In a letter to Sir Ernley Blackwell, Churchill stated that he maintained "the thousand odd weapons I have to keep for Police work alone".[42]

Subsequently, reference collections began to be extensively mentioned in the published literature, perhaps the earliest by Lucas. Lucas conducted substantial research into the effects of markings on bullets, including firing some 200 shots through a series of fifteen firearms, while Director of the Chemical Department (Government Laboratory) in Egypt. In a book published in 1921,[43] Lucas did not specifically discuss reference collections, but he acknowledges that: "the firing was kindly done by Mr. W. J. Harrison, Ordnance Department, Egyptian Army. The bullets were fired into cotton waste and retrieved one by one as fired and numbered as retrieved, the barrel being cleaned after each shot". There must have been some form of agreement between the Chemical Department and the Ordnance Department to obtain the reference firearms required for this testing.

Goddard, as part of his duties as the newly appointed Managing Director of the Scientific Crime Detection Laboratory (SCDL), travelled to Europe in 1929 to observe the activities of Scientific Police Laboratories (SPL) and Medico-Legal Institutes (MLI). He spent nearly three months travelling throughout Europe where he visited firearms experts such as Churchill and Pollard in England and Foury, Flobert, and Gastine-Renette in France. Goddard also visited numerous arsenals, firearm's manufacturers, and small arms collections. Goddard discussed his observations of the required apparatus (his term) for the study of bullets at the SPL's and MLI's. He noted[44] the need for: "comparison microscope, helixometer - which is an instrument for studying interiors of barrels, micrometers, chemical balances, reference collections of rifling statistics, specimen arms, ammunition, bullets, unfired and fired shells, powders, etc". He further commented that: "all European SPL and MLI Museums contain numerous specimens of firearms that have figured in crimes, and studies of varying scope are made of the parts played by these weapons".

It is clear from the literature that the collections have grown, and grown rapidly, over the years. Another early firearms examiner, Thomas N. Lewis, in an article[45] dated 1935, discussed the St. Louis, Missouri (USA) Police Department's Firearms Unit. Lewis wrote that "we have a special file for a library of cartridges, and a large collection of revolvers and pistols for reference are included in our research division".

In a pamphlet detailing a brief outline of the history of the Federal Bureau of Investigation (FBI) Laboratory, it discusses the formation of the laboratory. The laboratory was officially established on November 24, 1932. In a pamphlet,[46] published in 1982, under the section concerning equipment, it states "the shelves were to be used for displaying guns, cartridges, and similar items". It further states: "the Reference Firearms Collection and Standard Ammunition File furnish valuable information relating to the kinds of ammunition and the types of weapons from which fatal bullets were fired".

To date, the FBI Laboratory has in excess of 5,000 different types of firearms in their firearms reference collection.[47] In 1968, the Bureau of Alcohol, Tobacco and Firearms (BATF) established a firearms reference collection for the study, comparison and demonstration of firearms. By 1978,[48] the collection had grown to over 4,000 firearms. This collection is not open to the public, but is used by the Bureau and other federal, state, and local law enforcement agencies, as well as members of the international police organisation, as a source of information and evidence. As of April 2001, the BATF reference collection has over 5,200 firearms.[49] The rapid growth of reference collections was not restricted to nation-wide organisations. In 1985, Robert Christansen, then of the Los Angeles County Sheriff's (LASO) forensic laboratory said, "the firearms identification section maintains a constantly increasing firearms exemplar collection. The collection, started in 1962, now contains 3,523 firearms".[50]

These and numerous other references show that the existence of collections was worthy of mention but there is little comment as to their purpose or composition. A book by Nigel Morland[51] discusses some of the early history of 'forensic ballistics', which includes comments on equipment required by the examiner. When discussing the examination of firearms, he states that: "the method invaluable to the examiner is his record file against which his sample can be set for comparison with an elaborate collection of data already compiled". Later in the same section, he comments: "Any highly organised body concerned in the science would thus have references available for almost any possible eventuality".

Whilst Morland stresses the requirement for reference standards, Goddard highlights the need of a collection for training purposes. He states: "firearms identification is a highly specialised science, and as such, can yield good results only in the hands of one with the proper scientific training... Further, it must take a wide knowledge of arms and ammunition and their peculiarities as made throughout the world – not only in current, but in obsolete types".[52] Jack and Professor Charles Gunther discuss the training of firearms 'experts' and state that "the training of the experts must include experiments with ammunition fired from weapons collected at random, such as the weapons confiscated by the police departments".[53] The authors do not mention specific numbers as concerns the number of weapons to be collected for this purpose. They do, however, include discussion of several legal cases involving firearms identification to include the Iowa case wherein Goddard testified about the number of firearms in his reference collection.

In the book by Frank Jury and Jac Weller,[54] they discuss that in addition to a firearms reference collection, there also needs to be a collection of replacement parts. They state that: "every laboratory should have a weapons collection containing at least the most common firearms in use in that vicinity by criminals". When discussing rusted evidence firearms received in the laboratory for examination: "the rust is scraped and scrubbed off until the gun can be opened and unloaded, disassembled, and the internal parts cleaned and, if necessary, replaced in order to restore the gun to operable condition". In an article by firearms examiner John G. Sojat, he discusses firearms reference standards. Sojat states "in the firearms identification laboratory the ideal solution would be a collection of weapons, representative of all types commonly used in criminal behaviour, and complemented by an orderly file of standards fired in these weapons... At times this collection serves as a source of parts necessary to restore crime weapons into operating condition".[55] In 1965, J. McCafferty, then with the Metropolitan Police Forensic Science Laboratory, wrote an article on firearms. Concerning the subject of firearms, he states "I must emphasise that a good reference collection of weapons and ammunition is a necessity in order that experience and familiarity be gained and demonstrations made".[56] This highlights yet another use of a reference collection; that of demonstrations to the police, courts, and the like.

While the above shows the existence and uses of collections, there is no indication as to the size and composition. Captain Edward C. Crossman, an early pioneer firearms examiner on the West Coast of the United States (California, Arizona, Oregon, et al), was affiliated with the Bureau of Forensic Ballistics as their western representative. Crossman started working firearms cases in 1924 and later wrote about reference collections by saying "all one can do is to acquire all the possible specimens of commonly used guns and cartridges and tools for making them".[57] Crossman collected a relatively large reference library of firearms and cartridges during his career as an examiner. Hugh Pollard, a military officer and early English examiner who was a friend of Robert Churchill, wrote a lengthy article that appeared in 1924. In his article, he explained many of the details concerning firearms identification and discussed the following concerning reference materials: "at present, no centralised bureau exists where the police of the world can find standardised particulars of all pistols and firearms. My own private collection contains a fairly exhaustive series of one or two of each particular calibre".[58]

However, it was not unanimously considered essential to possess a firearms reference collection. Professor Paul Kirk and Lowell Bradford, in their 1965 book, specifically state: "It is desirable, but not necessary, to have an extensive collection of firearms. In contrast, it is absolutely essential to collect a large variety of bullets and cartridge cases from many types of firearms".[59] Another noted author, Professor J. Howard Mathews, produced an outstanding 2-volume reference set dealing with firearms identification that were published in 1962, then augmented by Volume 3 published in 1973.[60] His reference works contain extensive numbers of photographs, especially of obsolete, rare and uncommon firearms. The photographs were a method of augmenting firearms reference collections.

In 1995, Elizabeth Gillis and Carlos Rosati, of the BATF Laboratory in Rockville, Maryland, wrote about a method to 'augment' reference collections through use of digital imaging. They state "all firearms examiners would like to have access to a reference firearms collection (RFC) however, space restrictions as well as security and inventory of items such as firearms, or other Title 3 weapons, full automatic firearms, may not be in the best interest of a particular agency".[61] They discuss 'capturing' digital images of firearms to also have available within the firearms unit.

In a recent newsletter, Forensic Technology, Inc., manufacturer of the Integrated Ballistics Identification System, announced the official release of its Gunsights program. The announcement states "Forensic Technology proudly announces the official release of Gunsights, the ultimate firearms reference that provides the law enforcement community with a unique and powerful identification tool. Gunsights is a compilation of detailed information and high-resolution photographs of hundreds of current and historical firearms models, including many of the 100 most frequently traced firearms in the U.S. Available now on CD-ROM and ultimately on the

Gunsights Web site".[62] Beta versions of this program were available several months ago and found to be of some value in augmenting existing firearms collections.

In the recent past, two experienced firearms examiners have written textbooks[63, 64] on the subject of firearms identification. Interestingly, neither author mentions or explains the requirement for a weapons reference collection; although it is known by the author that both examiners have, within their respective laboratories, substantial reference collections available to them.

It is apparent in the literature that there is some doubt as to whether firearms reference collections are, or are not, necessary. In addition, the work of Matthews, Gillis and Rosati have shown a way in which reference collections, even if essential could be replaced by images. Whether such images would be an adequate replacement is not clear from the literature. Consideration of scientific disciplines other than firearms' examination shows that reference collections exist and, indeed, exist outside forensic science. Other areas of work using reference collections include botany, archaeology, anthropology and industrial collections, such as those of paint, plastic and textile manufacturers. Within forensic science, reference collections are commonly used to assist in, for example, tablet identification and the classification of footwear marks. However, the fact that other branches of science in general, and even of forensic science in particular, have reference collections is of peripheral significance only. The existence of such collections means that reference collections are perceived as being of value but may not justify them. The existence of other reference collections does indicate that the idea of a firearms reference collection is not unreasonable, but even if other reference collections are essential, this does not automatically make firearms reference collections necessary. It could be, for example, that firearms reference collections were never necessary or it could be that they could now be replaced by modern technology such as photographs or "digital images" distributed on CD-ROM.

Until now, no specific research[65] has been conducted to evaluate the requirement for firearms reference collections, their size and composition, the uses that are made of them or the attitudes of the firearms examiners regarding the use of modern technological aids. Research was conducted to explore some aspects of firearms reference collections. It was intended to find out if firearms sections do indeed have weapons collections and if so do they use them. If they are used, then what are they used for and will examiners consider using some form of imaging to supplement or replace collections of actual firearms. Clearly if collections do not exist or are not used then they are not necessary. If they do exist, a knowledge of the uses made would indicate whether it is technically possible to replace them with images and if the collections are maintained merely as a result of examiners being conservative in their approach to modern technology.

Assuming collections are maintained, it was decided to explore their size and composition. Are most collections small and comprised of firearms only likely to be encountered in the laboratory service area or were they more comprehensive and intended to cover all likely requirements? If the collections are large, do they in fact cover all requirements or is borrowing necessary? One other possible reason for a large collection is the retention of multiple copies, is this a practice and if so, why? Again, on the assumption that collections exist, then the firearms in them must be acquired. If they are purchased this represents a cost to the taxpayer over and above the cost of security such as inventory and physical control. To avoid any potential bias that might arise from national perceptions of the need for firearms collections, the survey would need to be conducted on an international basis.

METHOD

A four-page questionnaire, containing eleven multiple-choice questions was mailed, to the then approximately 650 members of the Association of Firearm and Toolmark Examiners (AFTE). These examiners, located in forensic science laboratories around the world, represent the majority of individuals practising the forensic speciality of firearms identification. The survey was designed to discover if firearms sections did, in fact, maintain firearms reference collections. If they did maintain a collection, what was the size and composition of the collection and what is it used for? The opportunity was taken to explore the views of firearms examiners about replacing firearms with images. The questionnaire is shown in Appendix 2. Where appropriate, the data was tested for significance using the chi-square test; see Appendix 4.

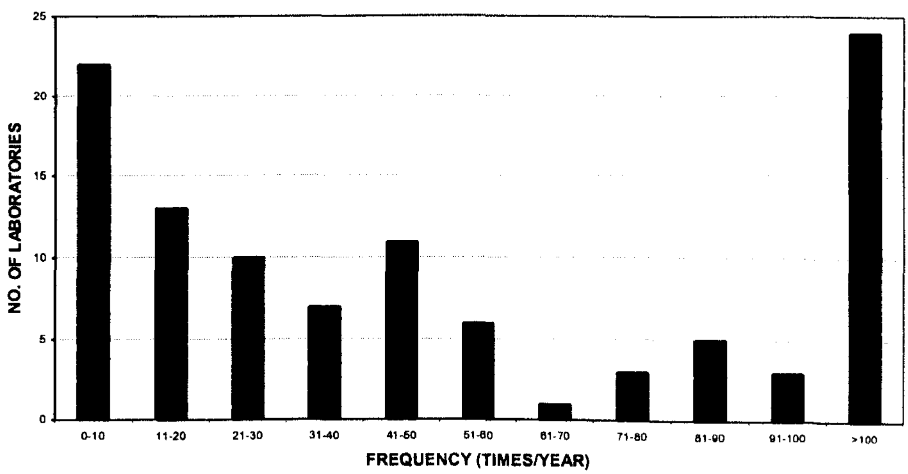
RESULTS

Replies from the survey were received from 110 forensic laboratories in eighteen countries. The questions and replies, shown below, represent the aggregate results from the 262 or 40% of the firearms examiners who received the survey. A total of 103 laboratories responded to question 11. The population, served by the laboratory, ranged from a small city laboratory serving 30,000 to a Federal laboratory serving over 275,000,000. In several instances, due to jurisdictional issues, several laboratories may eventually serve the same population. For example, in the author's laboratory, we may deem it necessary to send selected evidence to our State or Federal laboratories for certain types of analysis.

The aggregate total of the responding laboratories, which primarily represent the United States, Canada, European Countries, Japan, and Hong Kong, was in excess of 700,000,000 individuals. To date, the Association of Firearm and Toolmark Examiners (AFTE) has had few members join from Africa, China, India, Eastern Europe, or South America. Of the 110 laboratories responding, 92, or 84%, indicated they maintain a Firearms Reference Collection, Question 1. Seventeen laboratories, or 15%, indicated that they did not maintain a collection but that they had access to one. Only one laboratory, less than 1% of the laboratories responding, indicated that it neither had a collection nor access to one.

FIGURE 2.1

Frequency of use of the reference collections



Whether or not reference collections are used was explored in Question 7. In addition to exploring the frequency with which collections are used, the survey also investigated the variety of uses. Figure 2.1 above shows how often that the reference collections were reputedly used. A variety of uses were reported and most laboratories had more than one use, the results are summarised in Table 2.1 below.

TABLE 2.1

Uses made of the reference collection

Uses	No. of laboratories	% Total Use
Training examiners	60	11
Training others	58	10
Checking functioning	74	13
Checking specification	84	15
Demonstration to police	74	13
Demonstration to courts	46	8
Research	71	12
Repairs	77	14
Other uses	25	4

The attitude to using technology, such as photographs or digital images, were explored in Question 10. Would you 'subscribe' to a service that provided you photographs of firearms using optical disc technology such as one presently being considered in the United States by BATF; provided it were reasonably priced and updated on a routine basis? Of the 102 respondents to this question, 85 or 83% stated that they would subscribe to this type service provided that it was reasonably priced and updated on a regular basis. In many instances, cost of the service was a factor in determining whether the laboratory would subscribe to the service. Seventeen laboratories, or 17%, expressed concern about the potential costs to acquire the system. See Table 2.2

Question 9, explored the possibility of having only small reference collections in laboratories with ready access to a large central collection as required. Sixty-seven laboratories, or 61%, would subscribe to the concept of a centralised collection while 68 laboratories indicated that they already borrow firearms. See Table 2.2. Several laboratories responded that they felt there would be an unacceptable time lag in obtaining firearms, from a centralised reference collection. Some examiners were concerned about the cost in obtaining and returning firearms to the library.

TABLE 2.2

Acceptability of alternative data sources

Question	**YES (No. of Labs.)**	**NO (No. of Labs.)**
Do you borrow	68	19
Would accept a Centralised collection	67	36
Would accept Photographs	85	17

The size and composition of collections was explored as a part of Question 1 and the results are shown in Table 2.3 below.

TABLE 2.3

Composition of firearms reference collections

No. of Laboratories Serving each area →	**Urban Areas (21)**	**Mixed Areas (68)**	**Rural Areas (3)**
Firearm type ↓	**No. of Firearms**	**No. of Firearms**	**No. of Firearms**
Air guns	588	2,605	0
Rifles	2,436	15,181	25
Machineguns	129	2,030	0
Pistols	5,983	29,070	50
Shotguns	1,250	8,978	13
Home-made	97	506	0
Revolvers	6,282	23,152	35
Submachine guns	135	1,078	2
Suppressors	91	288	1
Other	3,215	2,451	0

Individual collections ranged in size from seventeen to five thousand two hundred and fifty with a median of eight hundred and a modal value of between five hundred and one thousand firearms. The classification of catchement area type, rural urban or mixed, was left to the responding examiners. This data was tested for any correlation between the type of area served by the laboratory and the composition of the reference collection. The data set is rather unbalanced data in that the numbers of firearms in collections serving different population types differ markedly. Some of the entries are zero, which could cause a test for independence between collection composition and type of population served to be seriously misleading when using the chi-square statistic. To avoid this, the data set was reorganised, the category "Other" was omitted and the remaining data reclassified as shown in Appendix 4.

The chi-square value was calculated to be 890 for 8 degrees of freedom, which is considerably greater than the critical value of 23.589 at the 1-% confidence level. This suggests that the composition of a collection is not independent of the type of population served. An examination of the residuals showed that urban areas had more than the average number of revolvers and less than the average number of rifles and shotguns in their collections. Rural areas had slightly more than average number of rifles and pistols and fewer than average automatic weapons and revolvers. The mixed areas had more than the average number of rifles, shotguns and automatic weapons but fewer than average revolvers.

Of the 110 laboratories that responded to the survey, only 68 or 62% indicated that they borrow firearms, this was ascertained in Question 8. They stated that they borrow them from other laboratories, gun shops, private individuals, and rarely from Museums. See Table 2.2 above. Few of the laboratories have any type of formal arrangement to borrow firearms on an 'as-needed' basis. The majority stated their arrangements are informal and usually on an examiner to examiner basis. In our laboratory, for example, if we request to 'borrow' a firearm for testing, it is accomplished between the examiners from both laboratories. The need to borrow may depend upon the size of the reference collection with those having the larger collections not needing to borrow at all. Comparing the need to borrow of laboratories with small reference collections with the need of laboratories with large reference collections, data in Table 2.4 was used to test this possibility:

TABLE 2.4

The use of alternative data sources

	Size of Laboratory Reference Collection				
Question	**>2000 Yes**	**>2000 No**	**<500 Yes**	**<500 No**	**Chi-sq.**
Do Borrow?	17	2	41	13	1.574
Would use Images?	17	2	45	8	0.217
Would use Central Collection?	9	10	39	14	4.070

At the 95% confidence interval the critical value of the chi-squared distribution is 5.02 for one degree of freedom. The results indicate that the size of the laboratory reference collection has no effect upon the need to borrow and although it may affect the frequency of borrowing, this was not investigated. Similarly the size of the reference collection does not affect the attitude of the examiners pertaining to the use of images. However, the laboratories with the larger collections are less enthusiastic about central reference collections than are laboratories with smaller laboratories.

One reason for large collections could be that laboratories have multiple copies of some, or even most, firearms within the collection. There could be a number of reasons for this for example training. This aspect was explored in Questions 2 and 3.

Approximately 50% of the respondents stated that they maintain multiple copies of selected firearms types for training and criteria for identification studies. Sixty percent of the respondents stated that they do not train examiners and only hire experienced and qualified personnel that have been trained elsewhere. For the 40% of laboratories that hire and train personnel as firearms examiners, the training is primarily conducted in the laboratory. Students are usually trained using the AFTE Training Manual, augmented by local training protocols. Laboratories that don't maintain multiple firearms, in their reference collections, stated that they borrow the firearms from the department armoury or other laboratories for this purpose.

One laboratory reported having 30 duplicate firearms in their reference collection, while another reported having 4 duplicate firearms. In those laboratories that maintain replicate firearms, the median was 10 to 12 copies.

Approximately 70% of the responding laboratories indicated that they maintained same type firearms for studies on model changes. Other respondents stated that, while they don't maintain same type firearms, they borrow these types of firearms from the department armoury or other laboratories, and use manufacturer's catalogues and brochures to maintain this information. Firearms for reference collections can be obtained in a number of ways including purchase, which would be a major investment. How they were obtained was explored in Question 4. The sources used to obtain firearms for the reference collections are shown in Table 2.5 below.

TABLE 2.5

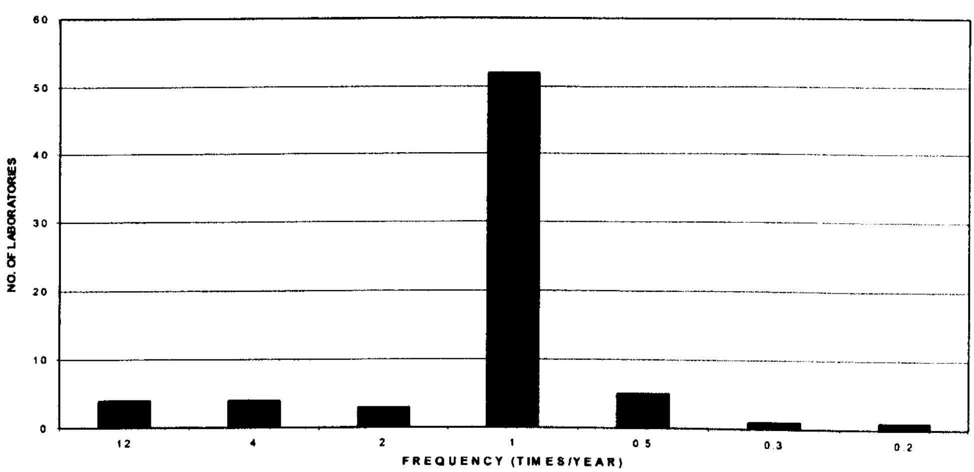
Source of weapons for Reference Collections

Source	**Number of laboratories using this source**
Courts	60
Donations	44
Other laboratories	24
Property rooms	36
Seizure	43
Purchase	14
Other	11

Some laboratories reported receiving up to 400 firearms per year while others received very few or no firearms. Many laboratories reported that, due to a lack of storage space for their collection, they use newly acquired firearms to replace current less-valuable firearms. The median number of firearms received by responding laboratories was 28. Interestingly, over 20% of the 92 responding laboratories did not have a legal authority to maintain their collection, Question 5. Some examiners stated that the collections were started before their employment and simply continued by them. Legal documentation was provided, by several laboratories, documenting their authorisation for a weapons reference collection. Of the 92 responding laboratories, 88 or 96% stated that they had an inventory control system for their collection, Question 6. Of the laboratories responding that they don't inventory their collection, it was determined they only had one or two examiners. The collection was usually very small and secured in a small locked room or safe, accessible only by the examiners. In 82% of these laboratories, the inventory procedures were computerised, However, there was considerable variation in the frequencies with which the inventories were carried out, and the results are summarised in Figure 2.2.

FIGURE 2.2

Inventory Frequency



The use of other collections and the acceptability of alternative data sources may depend upon the size of the laboratory's own collection. A comparison was made between the replies from laboratories having reference collections containing more than 2000 firearms with the replies from laboratories having less than 500 firearms. The data is summarised in Table 2.4 above.

CONCLUSIONS

It was determined that virtually all of the responding laboratories have a firearms reference collection. This demonstrates that there is a widely held perception of the need for such a collection and, since the survey was worldwide and included eighteen countries, this perception cannot be dismissed as a local aberration.

The collections are used for a variety of uses, which include training, repairs and demonstrations. Although the collections may be augmented by modern technology, which is a valuable supplement to the collection, the collection cannot be completely replaced by photographs and digital images. It was also determined that no matter how large the collection, there was still a requirement to borrow.

The perceived need for a collection contrasts markedly with the apparently infrequent use of the collection. If the results are taken at face value then the collections are, in many instances, subject to little use which would indicate that the perception of value is fiction, not fact. If the perception of need for a collection is in fact, correct, then the actual use of the collection is much greater than reported. This latter alternative is not as unreasonable as it may seem at first sight, since it may be that the data isn't rigorously recorded. Subsequent to the survey being conducted, examiners were contacted to request that they carefully evaluate the number of times they actually used their reference collection. A survey was also conducted at the author's laboratory to further define this number. In almost every instance, the initial survey numbers were found to be quite low in relationship to actual use. For example, it was determined that in our laboratory, we were actually referring to the collection an average of 5 to 7 times per day. Excluding various holidays, this figure represented in excess of 1,400 uses per year. (52 weeks per year x 5 work days – 12 holidays = 248 work days x 6 uses per day = 1,488 uses per year) Other laboratories verbally reported much greater uses of their reference collections than originally reported as well. The undercount as reported in the original survey is understandable, as the collection becomes an integral part of the examiner's resources.

It is the uses of the reference collections, which demonstrate that there is indeed a need for them. The uses are diverse, but perhaps the most crucial uses are those of repairs and research. As mentioned, photographs and other representations cannot substitute for the real firearm in these applications. If this is accepted, then a reference collection is essential. The size and optimum composition of a collection is difficult to define. Logically, there is no upper limit since the laboratories with the larger collections find a need to borrow; just the same as those with smaller collections, though the frequency of borrowing may differ.

The composition of the reference collections does seem to vary depending upon the type of population served. This could reflect the fact that the firearms are collected selectively to provide information about firearms encountered in casework. Alternatively, it could be that the firearms are in the collection because they are encountered in casework and therefore available for collection. This was not explored in the survey since it was felt that the answer would be a foregone conclusion. However, the fact that purchase is not a popular method for stocking reference collections suggests that availability could well influence the composition. The optimum size would be one, which provides the samples for the normal operation of the firearms section. Previously cited authors, such as Crossman and Sojat, were of the opinion that the examiner should reasonably have a collection that represented all the types of firearms commonly used in criminal behaviour. In the author's opinion, this is a sensible basis for defining the size and scope of a collection. The data indicates that this may be the case, but is open to the alternative interpretation that the collections here have been defined by the availability of firearms, rather than by selection.

This would include not only casework needs, but also additional firearms to provide for training and research. However even if a collection were established upon these lines, it would, over a period of time, tend to grow in size and diversity. This increase would arise from changing trends in firearms encountered in case work and could only be counteracted by deliberately disposing of surplus firearms. Inevitably, there will be occasions when firearms, which are unusual to the laboratory, will be encountered and it is these which complicate the definition of the reference collection size and composition. Indeed, it is the unusual firearms where reference material will be most frequently needed. The problems of unfamiliar firearms can be dealt with at present by extensive collections in each laboratory and loans from other laboratories and, perhaps to a greater extent than at present, by some form of imaging and information system. Certainly, the majority of examiners are prepared to consider this.

A central reference collection poses financial problems - who pays for it and how? While a central collection is, in theory, a viable proposition, an alternative would be a more diffuse collection where all laboratories contribute whatever they have to the common pool. However, whether a central collection is established or the system functions as at present, a catalogue of what firearms are located where would be of value.

In summary, the foregoing conclusions were reached:

1. A completed survey was received from some 110 forensic laboratories representing eighteen countries world-wide;

2. It was determined that the majority of laboratories either have a weapons reference collection or have access to a collection;

3. The laboratories not only have reference collections but use them;

4. Uses such as repairs, training and demonstrations show that the collections cannot be completely be replaced by modern technology;

5. No matter how large the reference collection, it is still necessary to borrow;

6. Images available through modern technology are a valuable supplement to the existing collections;

7. The vast majority of firearms are obtained at no cost to the laboratory. There is, however, a storage cost associated with collections.

Five or six laboratories used the results of this survey during the past three years to assist them in maintaining their reference collections. The collections were under scrutiny by non-laboratory administrators who felt that the reference collections were not a necessity for operational requirements. The survey and data obtained during the study were instrumental in convincing administrators to continue the collections.[66]

IDENTIFICATION OF CONSECUTIVELY RIFLED GUN BARRELS[67]

INTRODUCTION

One of the first recorded identifications of a specific fired projectile to a firearm, occurred in 1898 in Neuruppin, Germany. Professor Paul Jeserich, a gifted forensic chemist from Berlin, was requested by the Neuruppin district court to examine a bullet removed from the body of a murder victim to a revolver owned by a suspect.[68] Jeserich test fired the revolver and then carefully produced a series of photomicrographs of the murder bullet and the test fired bullet. When he carefully compared the photographs, he observed abnormalities on the bullets that indicated that both had been fired from the same firearm. His testimony was instrumental in the conviction of the defendant. His other interests, however, precluded his continuing further research into the area of firearm identification.

Additional research continued in this forensic field during the next twenty-five years by early self-trained examiners such as Sydney Smith, Robert Churchill, Calvin Goddard and several others. The adaptation of the comparison microscope, by Phillip Gravelle in 1925, for use in examining both firearms and toolmark related evidence provided the necessary instrument to realise the full potential of the science.

Four heavily reported criminal events, permanently established the discipline of firearm and toolmark identification in both the United Kingdom and the United States. These cases involved the assassination of the Sidar in Egypt and the murder of Constable Gutteridge in England; and the Sacco-Vanzetti murder case and the St. Valentine's Day Massacre in the United States. The ability of these pioneer examiners to identify both fired bullets and cartridge cases to a specific firearm was instrumental in establishing firearm and toolmark identification as one of the forensic sciences.

Current practices in firearm and toolmark identification training and actual laboratory casework is based on the hypothesis that fired bullets and cartridge cases can be positively identified to the gun that fired them. A forensic scientist trained in firearms and toolmark identification is often able to specifically identify, or eliminate, a firearm involved in a shooting when evaluated in conjunction with recovered evidence. The investigator, when provided with results of the laboratory examination, can often connect the perpetrator to specific crime. During the past 100 years, and more so in the past 50 years, extensive research has been conducted, and the results published, to support this hypothesis.

The identification of firearms related components, is accomplished, primarily using a comparison microscope. The examiner microscopically evaluates the fine scratches (striae) found on the bearing surfaces of the bullets or cartridge casings. These striations are considered to be accidental in nature and to arise from randomly occurring imperfections in the gun barrel. Since these imperfections occur at random, the pattern of striations is considered to be unique to a common origin such as a specific firearm or tool.[69] In the case of a fired bullet, the striations are impressed on the bullet by force and motion, as the bullet travels down the barrel of the firearm.

The majority of firearms, in the United States, are manufactured using a typical production-line style system. Numerous firearms items are fabricated utilising several different machining processes for each piece. The completed pieces are then sub-assembled, and then taken to a common location for final assembly, inspection, and testing. The final process, in the production process, is to test fire the firearm and ensure that it is functioning properly.[70]

During the manufacturing process, the tools used to produce the spiral grooves, or rifling, in the gun barrel wear causing minute imperfections to the bearing surfaces within the barrel. The continuous wear of the rifling tool causes these imperfections to change, which then causes similar changes to the corresponding surfaces of the lands and grooves. These changes make each gun barrel unique, no matter what rifling method is used.

The gun barrel, as the most significant part of the firearm, is made of several very special materials and undergoes unique processes during the manufacturing process. The metal used for modern gun barrels is a uniform mixture of carbon steel with specified amounts of manganese, nickel and other alloys. The addition of these alloys to the carbon steel[71] allows the manufacturer to obtain optimum hardness and durability. The special steel is formed into bar stock or cast into shapes designed for a specific firearm. The processes used to change the steel into a gun barrel are intricate and require numerous types of machining operations. The most important of these processes are Drilling, Reaming, Rifling, and Crowning.[72] In less expensive firearms, the manufacturer may produce the firearm using a cheaper barrel with a steel sleeve.

These manufacturing processes have a great impact upon the identification of the firearm to the bullet fired through the barrel. First, the bore of the barrel is formed by drilling with a unique deep hole bit designed to centre itself as it drills through the metal stock. A hole in the centre of the drill bit allows oil to flush metal chips out during the drilling process. The drilled hole is brought to it final dimension by passing a ream or broach through it. These tools remove very small amounts of metal, and true the size of the hole.

A number of grooves are cut, inside the drilled and reamed bore, and produce the final process - called rifling. In a particular firearm, the number of lands and grooves and direction of twist is according to the manufacturer's specification. As previously noted, these rifling specifications allow the examiner to evaluate fired evidence bullets to determine the potential class of firearm.

Grooves are cut in a spiral fashion, either to the left or right, to provide a gyroscopic spin to the fired bullet. The materials remaining between the grooves are referred to as lands. When fired, the bullet being slightly larger in diameter, is grasped by the lands and guided through its length, forcing it to turn on its own axis and imparting stability.[73] There are several methods used by manufacturers to rifle their firearms. Some of the methods used to cut the rifling grooves may include:[74]

The Hook Cutter – comprises a hardened metal hook that is drawn through the barrel to cut the grooves. This method cuts one groove at a time which requires that the cutter be drawn through the bore several times in order to cut all the grooves and to bring each groove to its final depth.

The Button Broach – is a hardened metal plug with a rifled cross section. This method is normally used on small calibre firearms making its grooves by compressing the metal as it passes through the bore. It forms all the grooves at one time to a set depth.

The Gang Broach – each button has a number of cutting edges corresponding to the desired number of grooves. This system uses numerous broaches attached to the shaft of the broach with each cutting a little deeper than the one before it. This broach cuts the grooves all at one time and, like the button broach, only requires a single pass through the bore to complete the rifling.

Crowning is the last major step in the rifling process. This process finishes the muzzle end of the barrel by milling it from inside out to form a slightly rounded surface.[75] A final step in preparing the barrel for assembly with the firearm is the step of milling the cartridge chamber into the breech end of the barrel. Although the chamber has little, if any effect on the class[76] or individual[77] characteristics of the bore, chamber marks[78] will often provide markings of value for identification purposes on fired cartridge casings.

The tools that finish a bore to its final dimension and those that machine the rifling are made of hardened steel. The cutting edges wear down during use and occasionally require sharpening. The cutting edges of these tools impart microscopic imperfections on the surfaces of the lands and grooves. These imperfections, in turn, create individual characteristics (striae) on the corresponding surface of the bullet passing over them. These characteristics are considered individual because the rifling tool continually changes which in turn alters the marks left on the lands and grooves. This change occurs through the length of the barrel, and from barrel to barrel, even barrels manufactured consecutively.

The Bullet

When a live round of ammunition is loaded into the chamber of a firearm and discharged, many events happen. The primer, which is located at the back or base of the cartridge, is struck by the weapon's firing pin. The primer detonates and ignites the propellant contained in cartridge casing. The burning powder creates gas, which builds to extremely high pressures and pushes outward in all directions. However, the steel around the chamber and breech contain this pressure so that its only escape is through the barrel by pushing the bullet out ahead of it.

As the bullet exits the cartridge case, it encounters the rifling just beyond the chamber. The lands dig into the bullet because the bullet is slightly larger than the inner bore diameter of the lands creating grooves in the surface of the bullet. The remaining surface material on the bullet swages into the grooves of the barrel. Individual striae are formed on the bullet by imperfections in the barrel scoring the bullet as it travels down the barrel. These striae potentially allow the examiner to relate the bullet to the gun that fired it.

Identification

The examiner, using a comparison microscope and oblique lighting, may identify the evidence bullet to the suspect firearm. The examiner initially evaluates and determines the class characteristics of the firearm and the fired bullet. They must be of compatible calibre, have the same width measurements and numbers of lands and grooves, and the same direction of spiral or twist. If both have the same class characteristics, the examiner can conclude that the bullet could have come from this gun or any other gun having the same characteristics.

The bullet is examined microscopically and the striations on the surface compared to corresponding areas on test bullets. The test bullets are obtained by firing at least two similar style cartridges through the suspect firearms. The two test fired bullets are microscopically compared to each other to determine if the patterns of striae are reproduced on both bullets. If they are then the examiner uses one of the test bullets to evaluate the evidence bullet. If sufficient agreement exists among the individual characteristics or, more specifically, the patterns of striae on the test and evidence bullets, the examiner can conclude identity and state that both the evidence and test bullet were fired from the firearm.

Firearms identification is somewhat similar to fingerprint identification. However, bullet and cartridge case identifications utilise groups or "families" of striae for identification instead of points, and identify the gun rather than the individual. Examiners utilise many of the same principles and criteria to arrive at their conclusions. The AFTE Glossary states: "the criteria used by firearms examiners for individualisation (identification), is subjective in nature, founded on scientific principles and based on the examiners training and experience".[79]

Reproducibility of Striae

Numerous studies support the contention of uniqueness utilised in multiple bullets fired from one firearm. Kirby[80] in 1958 fired 900 lead bullets from a .455 calibre revolver and was able to identify that all of the cartridge cases had been fired in the same weapon. However, he was only able to identify the first thirty bullets as being fired from the revolver. This was because the patterns of striations on the bullets were affected by the barrel becoming leaded during the test.

In a study conducted in 1972,[81] the author fired 501 223 calibre (5.56mm) full metal jacket (FMJ) projectiles from an M16A1 assault rifle. He fired the 501 cartridges as fast as the 20 round magazines could be changed and collected every hundredth projectile. It was possible to identify all the projectiles as having been fired in the same rifle. Although not originally reported, the work revealed that it was also possible to show that all the cartridge casings had been fired in the same rifle.

Ogihara, the author and others conducted a more extensive research study in 1977,[82] by examining 5000 bullets and cartridge cases fired from an U.S. Army issue M1911A1 45 (11.45mm) calibre semiautomatic pistol. The researchers used standard 45 calibre FMJ military ammunition for the project and collected every tenth fired bullet and cartridge casing for their examination. This study involved firearms examiners from three forensic laboratories and required a substantial amount of time to effect the comparisons for both the bullets and cartridge casings. The researchers were able to identify that all projectiles had been fired from the same pistol. A similar result was obtained through examination of the cartridge casings.

In another study, Shem and Striupaitis while being trained by the author in 1982,[83] conducted a similar study where they fired 501 bullets and cartridge cases from a

Raven Model P-25 25 (6.25mm) calibre semiautomatic pistol. They collected every 10th fired projectile and cartridge casing and examined them. They concluded that, although changes were occurring in the bullet striae, it was possible to identify projectile 1 to 501. They were also able to identify the cartridge casings to each other.

In February 2001, at the American Academy of Forensic Science Meeting in Seattle, Washington, Brett Doelling[84] presented the results of research that he had conducted involving multiple bullets from the same firearm. Doelling test-fired 4,000 cartridges through a 9x18mm calibre Makarov semiautomatic pistol and collected every 100th bullet. He concluded that, while the markings continued to change, the 4000th bullet was identifiable to the 1st bullet.

The studies, as well as others not mentioned in this paper, showed that an examiner could identify multiple bullets and cartridge cases fired from the same firearm. It should be noted that, however, striated markings may change rapidly, especially on bullets fired from inexpensively manufactured firearms. In this instance, as in cases where lead bullets have been consecutively fired, it may not be possible to identify the bullets. Although these studies were designed to determine the point at which successive bullets and/or cartridge casings could no longer be identified with the first, it provided concrete data to support early theories on the reproducibility of individual characteristics.

Variation between gun barrels

The previous studies have shown that the examiner has the potential to identify fired bullets and cartridge casings to the same firearm, even when multiple projectiles and casings have been successively fired. An area of concern, however, is the examination of projectiles and casings fired from different firearms. It is recognised that the striations are caused by imperfections in the rifling tools during the manufacturing process. The tools change during their use and potentially impart a continually changing set of striations. It would be expected therefore that the greatest amount of similarity would be encountered with firearms that are consecutively rifled using the same rifling tool.

In 1930, a rod of steel (barrel blank) was bored and rifled at an U.S. Government arsenal. A barrel stock was rifled, then cut into six pieces, to form six short barrels. One bullet was test fired from each of the six barrels and scribed with a secret marking. Colonel Goddard was given the six scribed bullets and six barrels for evaluation and examination. In this blind study, Goddard[85] correctly associated the scribed bullets to the appropriate barrel.

In 1970, Lutz[86] used two consecutively rifled and machined revolver barrels for a 38 Special calibre (9mm) Smith & Wesson Model 10 revolver. Three different types of bullet configurations, including lead bullets, were test fired and examined. The author, and others participating in the examination of the fired bullets, had no difficulty differentiating between the proper barrels.

Originally, there was concern that crowning the muzzle end of the barrel would be a cause for concern. Any imperfections in that area would deposit individual characteristics on the bullet as it left the barrel similar to the bore. In 1972, Murdock[87] compared bullets fired from the crowned barrels of four button-rifled barrels with other bullets fired from the same barrels after they had been recrowned. Although he observed some changes in the rifling, he could still associate the proper bullet to the specific barrel. Another set of test fired bullets was compared to the first set after the barrels were recrowned a second time with a similar result. This study demonstrated that crowning had a minimum effect on identifying fired bullets.

For a comprehensive study in 1981 Murdock[88] obtained three consecutively button-rifled 22 calibre (5.56mm) barrels from each of three different manufacturers. The nine barrels were machined to fit one bolt-action rifle. Thirty lead bullets were fired from each of the nine barrels and compared to each other. As in other studies, see below, the first few bullets fired from each barrel were not identifiable to each other. The remaining bullets, from any barrel, were identifiable to each other and could be distinguished from those fired in any other barrel.

In a study by Hall[89] in 1983, four barrels in 308 calibre (7.62mm) with polygonal rifling were used. Two of the barrels were consecutively rifled while the other two were randomly taken from the production line. Hall reports that he encountered no difficulties in identifying bullets fired in any of the barrels. He used three different brands of ammunition and the first five bullets fired from each barrel were used for stabilising the pattern of striations. This is necessary since the pattern of striations on the first few bullets through a new barrel can vary markedly. This variation in initial striation patterns is thought to be due to the residual debris remaining in the barrel during the rifling process. Bullets, fired after the first five, were identifiable to each other and could be distinguished from those fired in any other barrel. The author observed some change in striae, when comparing bullets that were sequenced further apart from each other, but this did not preclude identification.

During the past seventy years, a significant volume of research has involved the evaluation of test-fired projectiles and cartridge casings. This research[90] has included test firing the same firearm numerous times to evaluate the changes in the fired components or test firing consecutively rifled firearms to determine if projectiles could be associated with the correct barrel. In every research project, involving the examination of consecutively rifled barrels, the results established that examiners have the ability to identify fired components to the firearm. However this has not prevented there being challenges to this type of evidence in the courts.

Legal Challenges

In spite of the ongoing research conducted and reported in various scientific journals, some individuals continue to intimate that the examiner is not capable of associating fired components to the proper barrel especially in those cases involving consecutively rifled barrels. In other instances, some within the legal community simply refuse to believe that the field of firearm and toolmark identification is actually a science but merely some technical specialists trying to be scientists.

At a meeting held during 1972 in Los Angeles, California, the Lawyers Club[91] was told "it is actually impossible to prove that a bullet came from any particular gun, or to say with assurance which lands and groove made which markings in a gun barrel.....you just can't say definitely which bullet came from a certain gun". At a symposium for defence attorneys held in Eugene, Oregon during 1987,[92] a retired forensic laboratory director told the audience "that firearms examiners could not conclusively identify bullets fired from consecutively rifled gun barrels". Such accusations, if true, would obviate the use of firearm evidence in criminal investigations and court proceedings.

In recent legal challenges, within the Federal Courts (National) of the United States, and even some state courts, all aspects of science – to include forensic science – are under severe scrutiny. In 1993, in Daubert v. Merrell Dow Pharmaceuticals, and subsequent legal decisions, the U.S. Supreme Court has handed down new standards for determining the admissibility of scientific evidence in the Federal courts of the United States. Several states have already adopted the federal guidelines for the acceptance of scientific testimony.

Grzybowski and Murdock discussed the ramifications of the Daubert decision, and others[93] and they identified the four criteria that are imposed on scientific witnesses as being:

1.Testability of Scientific Principles,

2. Known or Potential Error Rate,

3. Peer Review and Publication,

4.General Acceptance in a Particular Scientific Community.

Several legal challenges to examiners in latent fingerprints and questioned documents have occurred since the Daubert ruling. It is reasonable to expect that firearms' examiners will be challenged in the near future.

Although previous research gives credence to the identification of consecutively rifled gun barrels, variables have limited the full range of the conclusions. In most of these studies, the examiner knew which barrels fired the test bullets. The examiner also could not verify the true consecutiveness of manufacturer, or orientation of each barrel with respect to rifling. A study that overcame these limitations was that of Brundage[94] who personally observed the manufacturing of 10 consecutively rifled pistol barrels for a Ruger P85 semiautomatic pistol. The Ruger pistol was selected on the basis of the current popularity of the 9mm cartridge and the manufacturers' willingness to participate. He subsequently sent bullets, fired from these barrels, to 30 senior examiners working in ASCLD-LAB accredited laboratories and asked them if they could relate the bullets to the barrels. In this study 29 of the examiners correctly ascribed all fifteen bullets to the ten barrels. The 30th examiner correctly ascribed fourteen of the bullets to the ten barrels and decided that the fifteenth bullet was so deformed that comparison was not possible.

This study demonstrated that it is possible for experienced examiners to correctly identify bullets to the gun barrel that fired them. However the study also has a number of shortcomings. Firstly the results were not statistically evaluated, secondly only a small number of examiners were tested and it is possible that the means they used is esoteric and only a limited number of persons have this ability. Thirdly the examiners were all senior, which suggests that they each have at least ten years experience, fourthly they worked in accredited laboratories where they are proficiency tested as a matter of routine. Finally all of the firearms examiners that participated in the original experiment worked in the Unites States of America.

This original research study was expanded to further examine the ability of numerous examiners to associate projectiles fired from consecutively manufactured gun barrels.

EXPERIMENTAL DESIGN

The experiment were undertaken to answer some of the following issues:

To determine if a firearm and toolmark examiner has the ability to correctly associate test fired bullets to consecutively rifled gun barrels,

To expand the test data base from the original 30 official, 30 unofficial, and seven pre-test participants and to extend this study to an international basis.

To provide test sets of known and unknown tests, from the 10 consecutively rifled barrels, for laboratories to use in their organisational training programs. A decision was made to prepare a total of 240 test sets for worldwide distribution,

To provide information to counter various legal challenges made by various legal authorities, and others, concerning the ability to identify bullets to firearms.

Materials and Methods

1. Pistol: One Ruger P-85 9mm calibre semiautomatic pistol, serial number: 302-06291 with one 15-cartridge capacity magazine. The same magazine was used during

the test firing sequence.

2. Barrels: Ten consecutively rifled 9mm calibre barrels manufactured by Ruger for the Ruger P-85 pistol. The barrels were marked 11 through 20, hereafter referred to as barrel numbers 1 through 10. The pistol and 10 barrels were borrowed from Commander Bruce Vander Kolk, Illinois State Police Forensic Science Command, Springfield, Illinois

3. Ammunition: Winchester 9mm calibre NATO, 124 grain FMJ ammunition, lot number: Q4312, Headstamp: WCC96. Twenty thousand cartridges were obtained, at a reduced cost, from Winchester Ammunition – A division of Olin Corporation, East Alton, Illinois,

4. Recovery system: One locally manufactured and vented 800 gallon water recovery tank, located in the firearms section of the Indianapolis-Marion County Forensic Services Agency (IMCFSA), Indianapolis, Indiana,

5. Ear and eye protectors for test firing, electric and scriber unit for scribing test bullets,

6. Envelopes of different sizes, computer labels for marking the test envelopes, padded packaging materials, pill boxes for collecting test fired bullets, and shipping containers,

Test Construction

Each test set included a control set, and unknown set of bullets. In the control set, it was known which barrel fired the bullet and comprised two bullets fired from each of the 10 barrels. The unknown set of fifteen bullets comprised at least one bullet from each barrel and no more than three from any one barrel. A total of 240 such test sets were prepared.

Prior to test firing the ammunition to prepare the test sets, the pill box containers were appropriately marked to indicate both barrel number and sequence of seven shots. For example, a container marked 1/1 would indicate barrel 1, test sequence 1, while a container marked 7/239 would indicate barrel 7, test sequence 239. Test firing commenced on July 8, 1999 and concluded on August 10, 2000 and was carried out by the author, Dave Brundage, or Mickey French – qualified firearms examiners - and ultimately involved shooting some 16,800 cartridges.

Seven cartridges were test fired for each test sequence. The test-fired bullets were retrieved from the water recovery tank, and the cartridge casings collected from a box designed to capture them during the firing sequence. The test-fired bullets and cartridge casings then placed in the appropriately marked pill container. After the test firing was complete, for a group of test sets, the marked pill containers were combined into 'groups' by barrel and firing sequence number. This combining allowed for the same relative amount of barrel wear, as the bullets were test fired during the same sequence. For example, every barrel – one through ten – and sequence 74 were assembled into one test set, 1/74, 2/74, 3/74, etc.

The sets of 20 'known' bullets were scribed on the base with the barrel number from 1 to 10. The 15 'unknown' bullets were scribed on the base with an alpha designator from A through Z. To ensure a random letter process, and to preclude using the same alpha character twice while scribing the 'unknown' bullets, a set of 26 3x5 cards were marked A through Z. The card set was shuffled, just before scribing the 15 'unknown' bullets, and the first 15 alpha characters utilised for marking the bullets. The process was further randomised by the author randomly deciding how many 'unknown' bullets – one, two or three - would be part of the set of the 'known' bullets. Each participant was then provided a test set consisting of 35 test fired bullets.

The test-fired bullets, after being individually scribed, were placed into coin envelopes that were previously labelled as follows:

KNOWN TWO (2) TEST BULLETS BULLETS FIRED FROM BARREL #1 0	QUESTIONED ONE (1) UNKNOWN FIRED BULLET – MARKED 'J'

The test sets were individually packaged according to the sequence of the test set being fired and continued until all 240 test sets were completed. A 10% random sampling of the 240 prepared sets were conducted before the sets were shipped to participants. This random sampling, using the comparison microscope, validated that it was possible to identify the 15 'unknowns' to the 'known' bullets.

Each completed test-set was sealed in a manila envelope, with instructions for completing the examination. The answer sheet requested additional information from the participant, such as years of experience, years and type of training, type of comparison microscope, and membership in forensic organisations. It may be, if the error rate was non-zero, that this could be correlated between training, experience and/or type of microscope. The test materials and answer form was packaged in a padded envelope for shipment. When the answer form was received from a participant, the answers were evaluated using the test set key. A letter of acknowledgement and the answer key were mailed to the participant for use within their laboratory.

Sample Population

In the expanded study, and because the author wanted to make this test widely available, notices of its availability were widely distributed. A letter announcing the availability of the test sets was distributed at the 30th Annual AFTE Training Seminar held in Williamsburg, Virginia, in July 1999. Another letter was prepared and distributed at the Annual ASCLD Training Symposium, held in Las Vegas, Nevada, in September 1999. Additionally, an announcement concerning the availability of the 10 barrel test was published in the AFTE Journal.[95]

Distribution of Tests

Test sets were distributed during the year 2000 at the 22nd Annual SHOT Show, the 31st Annual AFTE Training Seminar, and by Federal Express. To date, 204 test sets have been distributed to forensic laboratories in a number of first world countries.

RESULTS AND DISCUSSION

TABLE 3.1

Number of examiners reporting correct, inconclusive and incorrect results

Test Series	No. of Examiners Reporting Correct Results	No. of Inconclusive Results (Examiners, bullets)	No. of Incorrect Results
Brundage	66	1, 1	0
This study	133	1, 1	0
Totals	199	2, 2	0

Two hundred and one total responses have been received from examiners that participated in the two studies, see Table 3.1 above. In one laboratory reporting an inconclusive result they were unable to associate an unknown bullet with the known bullets due to damage to the projectile. Whilst they reported their finding on one bullet as "inconclusive", it would perhaps more appropriate to be reported as "unsuitable". In the second inconclusive result, the examiner simply felt that there were insufficient individual characteristics for a comparison to be made.

Evaluation

The majority of participants reported that the examination of the test set required between seven and nine hours. The shortest amount of time reported was three hours whilst the longest time needed for two participants was 30 hours.

In this type of testing once a bullet is ascribed to a barrel it is not re-examined so that this is sampling without replacement. Normally the probability of achieving a correct result by pure chance is calculated by the hypergeometric theorem. However in this test the situation is complicated by having up to three separate bullets ascribed to one barrel and the exact probability will vary depending where in the sequence of fifteen test bullets the additional bullets occur. A simpler form of calculation was therefore used. If an examiner took an "unknown" bullet and attributed it at random to a barrel then there would be a probability of 0.1 that the attribution would be correct. In the survey each examiner attributed 15 bullets to the 10 barrels correctly and the probability of achieving this by chance is 0.1^{15}, 1 in 10^{-15}.

Background information provided from the questionnaires provided insight about the total of 134 firearm examiners responding to the survey. Responses were obtained from 8 first world countries on four continents. In the United States, responses were received from examiners in thirty-one states.

The median number of years of experience in the field, for the 134 respondents, was 10.5 years, with the amount of time spent in training 1.8 years. Two of the participants were in training and had a total of six months experience each. The majority, in excess of 95%, of all responding participants indicate that they were trained under an 'on the job' (OJT) training scheme while a few examiners stated that their training was formal. The larger laboratory systems such as the Illinois State Police conduct more formal training than some smaller laboratories. When asked about the Specialised Firearms Techniques school, offered by the Federal Bureau of Investigation, slightly fewer than 24% responded that they had attended the school.

Almost 70% of the examiners used Leica (American Optical or Reichert) microscopes, while 27% used Leitz microscopes. Three percent used something else (Nikon, Moritex, etc.). The most prevalent type of lighting used by examiners was fibre optic at 49%. The use of both fluorescent and incandescent lighting was similar at 28% and 23% respectively. Many laboratories, however, reported that they use, or have available, the three lighting systems most mentioned in the questionnaire.

CONCLUSIONS

If the concept that the markings produced on bullets by consecutively rifled gun barrels is regarded as a null hypothesis then this data leads one to conclusively reject the null hypothesis. The results show conclusively that the markings on consecutively rifled barrels are different.

Two hundred and one firearms examiners, including those who participated in the original study by Brundage, participated in this research project. The project was designed to determine whether they could accurately identify 15 'unknown' bullets; obtained by test firing 10 consecutively rifled semiautomatic pistol barrels. In two instances, of the 3,015 bullets examined, participants considered the bullets as unsatisfactory for microscopic examination. The remaining 3,013 'unknown' bullets were correctly identified by participants to the provided 'known' bullets. The fact that there were no errors shows that the test procedure used to ascribe bullets to barrels is reproducible. The international nature of the study shows that the results are not produced by some localised misconception. However the lack of errors makes it impossible to estimate an error rate.

In turn this shows that there are identifiable features on the surface of bullets that may link them to the barrel that fired them. With fired bullets in good condition, and trained examiners, the identification process has a very low error rate; too low to be estimated in this study. In circumstances where bullets are deformed or fragmented, then the comparison process will be much more difficult and the error rate may rise significantly. Statements about the inability of examiners to associate fired bullets to consecutively rifled barrels were incorrect. Results of this study have provided the forensic community with additional supportive documentation in the field of firearm and toolmark identification. An expansion of this type study should be considered wherein bullets from other than the known barrels are included as part of the test-set.

With fired bullets that are in good condition, the current training of firearms examiners appears to be adequate and the choice of comparison microscope or lighting does not seem to affect the outcome.

THE EXAMINATION AND EVALUATION OF 617 FIRED CARTRIDGE CASINGS

INTRODUCTION

Shortly after one of the first recorded identifications of a projectile to a specific firearm, by Professor Jeserich in 1898, individuals initiated experiments to identify multiple fired components to one or more firearms.

In the United States in 1907, the first recorded examination of multiple firearms in conjunction with fired cartridge casings involved inspectors at the US Army's Frankford Arsenal.[96] The arsenal staff examined 279 30-calibre service rifles and 39 fired cartridge casings from a shooting incident. The rifles were test fired and the test casings examined in conjunction with the evidence casings. The staff reported that they were able to identify 33 of the cartridge casings to the rifles and their conclusions are an excellent example of early cartridge case identification.[97]

In the infamous case involving the assassination of the Sidar in Egypt,[98] Sir Sydney Smith discusses his examination of evidence from the crime scene, a 32 calibre (7.65mm) Colt semiautomatic pistol and fired cartridge casings. Of particular note is his test firing 24 additional Colt pistols to use as a 'control' in his examination of the evidence and his tests of the suspect firearm. Smith writes in his book the following, "the extractor and ejector marks were characteristic of any Colt pistol, but there were also details of a purely individual nature. I used twenty-four other Colt pistols as controls, and in no other case was an exactly similar extractor mark produced". [99]

In another infamous case, involving the murder of Constable Gutteridge,[100] experiments were conducted using multiple firearms to evaluate the markings found on the fired 455 (11.45mm) calibre evidence cartridge casings. Churchill, in conjunction with specialists from Woolwich Arsenal, arranged for a total of 1,374 Webley revolvers to be test fired and the breechface markings compared to the evidence casing. Churchill was able to conclusively state that the evidence firearm produced the markings on the evidence casing.[101]

In a very publicised case, involving the kidnapping of the child of American aviator Charles A. Lindbergh in 1931, the examination of toolmark evidence provided crucial evidence during the murder trail of the alleged kidnapper. Although this specific toolmark was in a wood matrix, its importance is that it involved the analysis and examination of multiple toolmarks to determine identity and is therefore analogous to the examination of fired cartridge casings. A home made wooden ladder, used to enter the home and kidnap the child, was observed to have toolmarks on one of the planed surfaces. The examiner, Arthur Koehler of the U. S. Forest Products Laboratory, requested and obtained a sample of planed wood from 1,595 timber mills throughout the United States. He carefully and systematically examined evidence from the ladder, in conjunction with the 1,595 wood samples, and was able to identify the wood planer that had made the toolmarks. During the murder trial in 1935, this evidence was crucial as it demonstrated the fact of individual wear in metal and how it could be matched with the material, in this instance wood, on which it had been used. This was the first recorded evidence example of a piece of planed wood being identified to a planing machine and was instrumental in the defendant being found guilty of murder.[102]

In a case in England in the early 1950's, an individual was shot and killed by someone using a 25 (6.35mm) calibre pistol.[103] During the course of the extensive investigation, and in an effort to determine the murderer, a total of 524 similar pistols were test fired and evaluated in conjunction with the evidence. Although none of the test fired pistols compared to the evidence, it further validated the concept of toolmarks being unique.

In 1973, an U. S. Army Captain was shot and killed while standing in his tent in a bivouac area. The assailant used a 223 (5.56mm) calibre M16A1 assault rifle to shoot at the Captain's shadow in the tent. The investigators seized a total of 47 M16A1 rifles from personnel in the bivouac area. The rifles, and fired bullet components recovered during the autopsy, were forwarded to the US Army Criminal Investigation Laboratory at Fort Gordon, Georgia. Special Agent John G. Ward, Sr., senior firearms examiner for the laboratory, test fired the 47 rifles and microscopically compared the test-fired bullets with the evidence bullet fragments. Ward was able to identify the rifle used to shoot and kill the Captain. The suspect, a disgruntled soldier, was found guilty of murder.[104]

In 1984 and 1985, in the Federal Republic of Germany, three individuals were shot and killed in three separate events. The killer, using a 9mm Luger calibre pistol, killed the individuals to then steal their automobiles and then rob banks in small German towns. The killer would rob the banks using a pistol and a heavy hammer, so the events quickly became known as the 'hammer – murder' cases.

Evaluation of the characteristics, of the fired bullets and cartridge casings, were later determined by laboratory examiners, to be consistent with class characteristics of a Walther, Model P5, semiautomatic pistol. As this was the type of firearm carried by German police officers, and due to considerable public pressure, a decision was made to test-fire all Walther Model P5 pistols for examination by examiners from the Forensic Science Institute of the Bundeskriminalamt (BKA).

Test-firing all Model P5 pistols, then currently used by police officers from the State of the Baden–Wirttemberg, a state within Germany, involved a total of 7,862 pistols. Over 2,000 Model P5 pistols had already been test-fired and the fired components sent to the BKA Laboratory. Examiners from the BKA and Baden-Wirttemberg Laboratories, working together at the BKA Laboratory, examined fired components present at the laboratory plus those being submitted on a daily basis.

This volume of comparison work, using standard forensic microscopic techniques, was very complicated and time consuming. This event occurred prior to the introduction of automated systems that have the potential to assist examiners in sorting through large volumes of evidence.

After months of labour intensive microscopic comparisons, examination of test ammunition from the 3704th pistol, with evidence from the murder scenes, revealed that this was the pistol used to fire the bullet and cartridge casings. The findings of the examiner were quickly verified and the information communicated to officers investigating the murders. Before the investigators could interview the officer that the firearm was issued to, he murdered his family and committed suicide.

Dr. Klaus Dieter Grooß, head of the BKA firearms section, wrote the following about this incident, "It is believed that this investigation is one of the most comprehensive comparisons of firearms evidence ever carried out in a real shooting case. In our opinion, the most important result as far as the individuality of marks on fired bullets and cases is concerned is the fact that never during the investigations of 3,703 police duty pistols and 221 pistols from other sources - altogether approximately 4,000 pistols of the same manufacturer, same model, approximately the same age and same degree of wear, - marks were observed, which left no doubt that they were identical to those observed on the evidence ammunition. We were able to find the one pistol, which fired the fatal, shots out of an assembly of 4,000 others. So far this investigation is an excellent example for one of the basic principles on which our work is based: the individuality of marks on fired bullets and cartridge cases".[105]

The above cited incidents, especially the 'Hammer-Murder' case, along with a substantial body of literature that relates to the uniqueness of firearms and toolmark identification, further validates the ability to specifically identify items to one another. This ability to individualise by forensic examiners, however, is continuing to come under scrutiny especially in the United States.

The cited research provides credence to the identification of fired evidence bullets and cartridge casings to a specific firearm. A decision was made to add to this body of knowledge by conducting an additional experiment that involved the examination of fired cartridge casings. The cartridge casings were obtained by test firing 617 Glock, Model 17 or 19, 9mm calibre, semiautomatic pistols, and microscopically comparing the casings to each other to validate that uniqueness and individuality exist amongst each casing. To validate the potential for utilisation of automated digital imaging systems, the 617 casings were then digitally imaged into an Integrated Ballistics Identification System (IBIS) for correlation – See Chapter 5, Automation, for results.

EXPERIMENTAL DESIGN

The experiment was undertaken to answer some of the following issues:

> To determine if a firearm and toolmark examiner has the ability to correctly identify test-fired cartridge casings to each other, and to the exclusion of other like-type cartridge casings using conventional comparison microscopy;
>
> To determine if an automated system, such as the Integrated Ballistics Identification System (IBIS), has the ability to correctly associate test fired cartridge casings to cartridge to each other and to the exclusion of other like-type cartridge casings;
>
> To provide information to counter various legal challenges made by various legal authorities, and others, concerning the ability to identify components fired from like-type manufactured firearms.

One could argue that the experimental design for this project was flawed, considering that the author was personally involved in test firing the 617 Glock pistols. Although not a blind study, microscopic evaluation of the fired casings still required that the examiner observe sufficient individual characteristics for identification.

MATERIALS

1. Glock, Model 17 or 19, 9mm calibre, semiautomatic pistols. The laboratory identifier, serial number and model number of each pistol is indicated in Appendix 5. Each pistol was test fired using a Glock 15-cartridge capacity magazine provided with the pistol. Of the 617 Glock pistols, 456 were Model 17's and 161 were Model 19's. The pistols were approximately five years old when they were exchanged for the Glock, Model 22, 40 calibre pistols.

2. Ammunition: Federal, 9mm Luger calibre, 124 grain FMJ projectile, catalogue number: 9AP, lot number: 22A-9712, Headstamp: F C 9MM LUGER. A total of three thousand (3,000) cartridges, obtained from the Indianapolis Police Department (IPD) Firearms Training Unit, were used to test fire the pistols. A total of 2,468 cartridges were used for test firing.

3. Test-fire range: The pistols were test fired at the Indianapolis Police Department Range Facility, Indianapolis, Indiana. The range consists of several cement block enclosures that have baffled roofs to prevent fired bullets from exiting the roof of each individual range. At the end of each enclosure is an earthen mound approximately 20 feet high.

4. Microscopes: One Leica Forensic Comparison Microscope, Model K2700, serial number 254, equipped with several objectives to allow viewing from 4X to 80X magnification. The microscope is equipped with a Sony Colour Video Camera (CCD), Model DXC-151A, serial number 103119, a Sony Colour Monitor, Model PVM-1353MD, serial number 2000218, and a Sony Colour Video Printer, Model

UP1800-MD, serial number 12276. One American Optical Stereoscopic Microscope, Model 570, serial number 124775.

5. Ear and eye protectors for test firing, electric scriber unit for scribing the test fired cartridge casings.

METHOD

The pistols were test-fired on eight days during a one-month period in 1997. IPD Range personnel randomly provided the pistols as they were pistols being returned to the company. Prior to each pistol being fired, it was inspected for safety and the serial number and model recorded onto a small coin envelope. The magazine was loaded with four cartridges and then fired by the author, John Mann, Dave Brundage or Mickey French. Immediately after firing the casings were recovered and sealed in a marked envelope.

Once the available pistols were test fired, and the cartridge casings collected, the envelopes were randomly assigned a number from 1 to 617. A list was prepared indicating the assigned laboratory identifier, plus the serial number and model number of each pistol. The casings were individually removed from each envelope, scribed with the appropriate laboratory identifier, and placed in plastic ammunition trays for microscopic examination.

The casings were placed in plastic ammunition trays, each capable of holding forty cases; they were arranged so that half of one set was in one tray and the other half in another tray. This arrangement allowed the casings within one set to be compared against the other. Each plastic tray therefore held 20 half set of casings.

A stereoscopic microscopic was used to align the cases for study of the breechface area. Breechface markings such as the extractor, ejector, and other markings were evaluated during the experiment but the firing pin impression was the primary area of interest for comparison microscopy. The firing pin impression was selected inasmuch as the Glock firing pin impression produces an excellent toolmark for evaluation purposes. Each of the four casings in every set of the 617 fired casings was microscopically examined to ensure that the firing pin impressions contained identifiable markings suitable for comparison purposes.

After the preliminary screening was completed, the casing identified as number one, was designated as the primary casing, and placed on the left side of the comparison microscope. Using the right side of the comparison microscope, the remaining 616 fired casings were compared to the primary casing. The microscopic evaluation of each casing, against the primary casing, required approximately 10 minutes per casing.

RESULTS AND DISCUSSION

All casings were correctly individualised which further validates the ability of a trained examiner to examine multiple specimens and correctly identify each one.

The fired casings were digitally imaged and entered into IBIS for correlation against each other to determine if the instrument had the capacity and capability to handle the numbers of casings, and to achieve the correct correlation, see Chapter 5.

CONCLUSIONS

Crime laboratory personnel have routinely identified fired cartridge casing with suspect firearms during the past 75+ years. Recently the accuracy of this type of examination has come into question, especially if multiple firearms were used in the offence under investigation.

Examination of all of the fired cartridge casings, against a casing designated as the primary casing, verified that each was identifiable and unique. This supports the concept of the ability to individualise fired cartridge casings against the firearm that fired them. This data is one of the few published studies of this type and supports the findings of the study of P5's in Germany and should be helpful in supporting the criteria for firearms and toolmark identification.

The error rate could not be calculated since in this study none occurred.

AUTOMATED TECHNIQUES IN FIREARMS IDENTIFICATION

INTRODUCTION

In the past several years, especially in the United States, legal rulings such as the previously mentioned Daubert from 1993, and its successor Kumho in 1999 have encouraged some defence lawyers to argue that forensic science is not scientific. To date, legal challenges have been raised against latent print and questioned document evidence.[106] It is reasonable to expect that these types of legal challenges will soon include firearm and toolmark related evidence. In the past few years, automated digital imaging instrumentation has become available to the forensic science community; the equipment has the potential to provide reproducible and unbiased comparisons of bullets and cartridge cases. This is in contrast to human examiners who may be under pressure from casework, ill or tired, or simply insufficiently skilled.

At a meeting held in 1934, Goddard recommended that a central location be established, where bullets removed from homicide victims would be sent for analysis, and reports issues as to calibre, type of bullet, and type of firearm used. He felt that the centralisation of the examination of fired components would provide a link between unsolved cases and ones currently under investigation. Goddard further explained that firearms encountered during investigations could then be submitted for comparison with the bullet file and a report issued to the agency submitting the evidence.[107] He felt that this centralised file would assist by providing valuable intelligence to the investigator. Although his idea was rejected, the concept of local and state laboratories maintaining an 'open case ammunition file' was initiated as forensic laboratories were established within the United States. The files, consisting of fired bullets and cartridge cases submitted from various crime scenes, were examined against firearms submitted to the laboratory. The arrangement was, however, not satisfactory as it required a large amount of time to microscopically evaluate 'open file' components. It also failed to account for criminals committing crimes in nearby localities served by a different laboratory. On some occasions, however, examination of open file components did result in identification between bullets, cartridge casings, and evidence firearms.

The results achieved, in linking a limited number of crimes, did demonstrate the potential value of the concept. To realise the full potential, however, it would be necessary for the laboratory to cover much larger catchement areas for the examinations to be feasible. In theory, it would be possible to employ the large number of examiners needed to carry out the lengthy microscopic examination; but this was not a realistic economic proposition, then or now. Although the requirement for criminal intelligence was proven, there was a need for good communications and an automated examination of fired ammunition components, if this intelligence were to be provided.

Other than firearms units maintaining 'open files', and checking components against submitted firearms, little research evolved in the area of automation. This was due, in part, to the lack of instrumentation to aid in the development of automating files. Some laboratories did, however, photograph breechface markings and selected areas of the fired bullets in their open case files and retain the photographs in an attempt to assist the examiner with visual recognition in searching their 'open-case' files. In

March 1989, the Metropolitan Police Department (MPD), Washington, D.C., faced an ever increasing backlog in shooting related cases.[108] To obviate the overwhelming backlog of several hundred cases, a task force was created and the examiners produced black and white photographs of fired cartridge casings. The photographs were grouped, according to calibre, on exhibit boards around the laboratory. This allowed an examiner to photograph cartridge casings, and then physically compare the photographs with those displayed along the walls of the laboratory. If the examiner observed a photograph on the wall, that appeared to have some of the same microscopic characteristics of his photograph, he could physically obtain the casings and microscopically compare them. In numerous instances this type of inter-comparison occurred and examiners made several identifications.

In 1992, Moran while in the San Mateo, California forensic laboratory established a photographic 'open case file'[109] in response to a substantial increase in the homicide rate in their service area. They photographed submitted evidence cartridge casings and attached the photographs to worksheets for easy reference. Using this manual system, a total of 441 items of evidence were entered in the file and some 86 associations made (19.5%). Although this procedure doesn't represent true automation, it represents the use of categorising numerous items of evidence as suggested by Goddard. One difficulty was the photographs showed only a small portion of the bullet whilst comparisons are normally based upon the examination of the whole of the bullet surface.

In the 1930's and 1940's efforts were made, by various manufacturers, to develop a method to photograph the entire cylindrical surface of a fired bullet onto one film plane. This was accomplished by rotating the bullet in front of the camera lens while moving the camera film. The film was synchronised with the rotation of the bullet to produce a complete record of the bullet surface. It was envisioned that photographs of both test and evidence bullets could then be overlaid for comparison by the examiner. Although given different names by their respective manufacturers, such as the Pantascopic, Belaunde, Bullet Periphery, or the Balliscan, the cameras are referred to generically as Panoramic Bullet Cameras.[110] In 1971, the firearms identification division of the U.S. Army Criminal Investigation Laboratory, Fort Gordon, Georgia, received a Balliscan Camera for testing. The camera, then manufacturer by the Hycon Company of Monrovia, California were probably the last of the panoramic bullet cameras. Unfortunately, the camera only worked with undamaged bullets since it had a limited depth of field, the 70mm film was very costly, and it was slow to set up.[111] The cameras never received wide acceptance within the crime laboratory, and none are being commercially produced at this time.

Alternative image acquisition systems were being tried. In 1950, John Davis adapted a Profilograph, then being used by the Timken Roller Bearing Company of Canton, Ohio to observe bearing surfaces. The modified instrument was a "photo-recording instrument making use of the optical lever for vertical amplifications"[112] which he called the Striagraph. Davis encountered numerous problems in using the striagraph, especially when attempting to produce a striagram record of the surface of a fired bullet. The instrument never went beyond the experimental stage but could certainly be considered a forerunner in the attempt to automate some elements of firearm and toolmark identification.

In 1964,[113] the design for a prototype computer-based firearms examination system – Ballistics Identification System (BALID) – was announced. The system consisted of an electro-mechanical scanning component, a small computer, and computer programs. The scanning unit was the Talysurf-4 instrument, a solid state, electro-mechanical scanner with filters to electronically flatten the curve of the bullet. The system used three computer programs. One provided output from the scanner, and produced indices of the ballistics markings, which are the numerical values representative of such markings. The second program stored the information in the appropriate bullet files maintained on magnetic tape. The third program was used to conduct a search, using an elementary algorithm, from the test bullet to find the most possible match, the firearms examiner making the final judgement as to whether a bullet is from the same firearm. One of the hopes for the system "is that it will be possible to use it to amass statistics on just what constitutes a true match, and what degree of approximation constitutes a match with what degree of probability. When we can establish this forensic side of the problem, the examiner will have an incontrovertible basis for his testimony". In spite of its lack of commercial success, the BALID System was a pointer to the future. The system incorporated not only imaging but also, for the first time, computer storage and retrieval of data. It highlighted some of the problems of automating firearms examination such as the need for statistics and algorithms to enable a comparison to be made between images.

Image Acquisition

With the advent of computers it became possible to acquire images by attaching a video camera to a microscope. The computer could store the image that was in a suitable format for automated comparison. A number of attempts were made to develop such systems but not all entered operational use. One system being developed by Warren[114] foundered through lack of funding and another, developed by Uchiyama[115] was used to explore striation-matching criteria on fired bullets.

In 1989, the FBI Laboratory had a contractor develop an automated system, called Drugfire, to link drug-related shooting incidents.[116] The system used a video camera, attached to a microscope to digitally acquire images of fired cartridge case primers. After data acquisition the system computer, used a proprietary algorithm to search the database and provide the examiner with a candidate list of possible matching casings. The system was extended to include the imaging of fired bullets by developing a rotating stage for the microscope; this unit being called 'Rotoscan'. It was, however, merely a digital version of the panoramic cameras and, like them, had problems imaging deformed bullets. In addition to providing an electronic database, the FBI also provided a computer network to inter-link local and surrounding area laboratories. The use of computers to automate elements of firearms identification occurred, in the author's judgement, because of two issues. Firstly, there was a keen awareness within the overall forensic community, of the need to develop a system that would aid the examiner in sorting through the volumes of evidence. Secondly, and more importantly, was that computer technology had advanced to a point that it was economically feasible to provide the necessary 'computing power' for automated systems.

At essentially the same time as the introduction of Drugfire, another system, eventually called the Integrated Ballistics Identification System (IBIS), was being developed. In contrast to Drugfire this system was intended to image fired bullets. Like Drugfire the system used a video camera to acquire the image and a computer to store images, to search a database and provide the examiner with a candidate list of possibly matching bullets. It was also capable of being integrated into a computer network so that the database and information could be shared across a wide area. "Inherent in this technology is the ability to create data bases and to access them remotely. This gives rise to a whole new series of examinations, the conduct of which has not been feasible up to this point. The concept of the "global village" will have a significant impact on the way law enforcement agencies in general and firearms laboratories in particular conduct themselves in the very near future. Their degree of success in this regard will be determined, in large measure, by their ability to incorporate new technologies".[117]

The camera used by IBIS for imaging bullets is essentially the same as the previously mentioned panoramic camera systems. IBIS, however, uses two lasers to adjust the focus of the microscope lens during bullet rotation. This system obviated earlier problems associated with fixed focus mechanisms, such as Rotoscan, and allowed imaging of moderately damaged bullet.

Other systems have also been used to image fired cartridge components. Gardner obtained 13 bullets test fired from four 38-calibre revolvers. He used a Scanning Electron Microscope (SEM), that "...has the advantages of greater depth of focus, and an electronic signal which is convenient to use as computer input",[118] to acquire images of bullet surfaces.

Gardner scanned the central portion of the bearing surface of each bullet. The use of a SEM, with its excellent depth of field, allowed badly deformed or fragmented bullets to be imaged and a derivative of the average scan produced. He concluded "the quantified information used in the verification procedure also provides a basis for classifying bullets in an ordered file, which allows efficient search for a limited number of verification candidates."

Other researchers have also evaluated the use of SEM technology within the forensic laboratory and have actively used the SEM in operational casework and reported their findings.[119, 120, 121, 122] Although the research by Gardner revealed potential for an automated bullet system using SEM, the system was never widely used. This may be due to the expense associated with acquiring and maintaining a SEM and the associated computer hardware and software.

An alternative other than the striagraph to conventional optical imaging is holography. This was initially used for fingerprint identification but attempts were made to adapt it to the examination of fired cartridge components.[123] When used for fingerprints a transparency of a fingerprint is made and a low power laser is passed through this transparency and caused to interfere with another portion of the laser beam. A second transparency, called a 'filter', is made of the resultant interference pattern. To effect a comparison, a laser beam is passed through a transparency of a fingerprint and a filter. If the filter were made from the same fingerprint, a bright light would result. If the filter were made from a different fingerprint, a much more diffused pattern of light would result and it is a simple matter to connect a photocell to detect this bright spot of light. With this system, a rapid mechanical search of a fingerprint file may be made. The same basic system of transparencies and filters was to be used for the comparison of fired bullets. The comparison of bullets would be based more on pattern recognition rather than on a point by point identity used for fingerprint identification. Lack of funding prevented development of this system.

Another way of using lasers is to scan the surface topology of a fired bullet. One way of doing this is to use light reflected from the bullet surface to keep a lens in focus. The topology of the surface is obtained by recording the lens movement as the surface is scanned.[124] This technique was found to be sensitive to small details, reproducible and unaffected by the surface material or angle of incidence of the light. However, the technique is slow compared with optical methods. It does have one big advantage that of producing a three-dimensional image where as the optical techniques can only produce a two-dimensional image. Potentially therefore much more information is available with this technique than with others. Gardner[125] explored the value of three dimensional as opposed to two-dimensional images and suggests that the vertical profile of striations is more characteristic than their positions.

Another method of obtaining a three-dimensional image, with all its advantages, is to use confocal microscopy. There are currently two systems that have been reported in the literature as being under evaluation. One system uses a method that scans the surface of an object, in this instance, a fired bullet; multiple times at different focal point. Each of the individual scans, which are two-dimensional, is stacked with others to form a three-dimensional composite image.[126] Whilst in the other system, a laser beam is projected through a lens onto the surface to be measured. The reflected light displaces the imaging lens to maintain a given focal plane.[127]

Comparison

Image acquisition is only one part of a fully automated system; as described with the BALID System it is also necessary to have programs that will enable the computer to carry out comparisons. Underlying such programs are mathematical models describing the striation patterns.

Brackett used a variety of random number models to describe striae position and used these to calculate various values of probability of matching. He constructed an ideal model and that it has been observed that run distributions of striated mark comparisons are in accord with the relationship. Brackett felt that suitable models might evolve into mechanical models; which may then be compared with actual toolmarks. Brackett concluded: "The model method is tedious, and not of immediate application to forensic problems; however, it gives valuable insights into the properties of the striated mark comparison. It is hoped that the above principles and processes can be **computerised** so that more properties can be determined and practical procedures of use to the criminalist may be developed".[128]

This work was taken up by Dr. Werner Deinet who studied several probability theory models based on the premise that if two patterns that are similar to a certain degree, what is the probability that such a similarity or an even greater one occurs at random? He applied the models to a total of 40 impressions of grinding marks by digitising the data from the grinding marks and testing it against his models using a minicomputer. In testing the models, he found that: "a high degree of similarity between two sets of marks is not sufficient to identify a tool if it is highly probably that the similarity may occur by chance."[129] He also found that, while there were some areas of validation, the probabilities provided by the models are so small that they can not be statistically ascertained.

Biasotti[130] proposed a very different model based upon the length of the 'runs' of consecutively matching striations. In his experiments, Biasotti test fired several 38 calibre revolvers and then studied the striations on the bullet surfaces. He observed that bullets fired from different revolvers had several short 'runs' of consecutively matching striation while bullets fired from the same revolver had fewer, but very much longer, 'runs'. Biasotti discussed[131] the overall concept of automation and felt that the greatest potential for automation was the ability to generate the fundamental data needed to develop objective pattern recognition criteria in determining identity or non-identity in striation matching.

In another approach to potentially automating bullet identification, Uchiyama[132] discusses an automated system that he had developed named the Automated Landmark Identification System (ALIS). This system images the striae in the landmarks on fired bullets using a CCD camera; and an image processor calculates the histogram of intensity of the image. A personal computer convert the histogram data into "bar code" like stripes and these "bar codes" are compared to any other similarity recorded and stored data. The comparison is based on the percentage of striations in the two images that match. Interestingly, he addresses the issue of what constitutes a matching striation since on two bullets they may vary slightly in width or position. In the comparison process, the data of the landmark with the narrower width is moved from left to right, and the percent match of striae, sum of square between the histograms of image data and sum of depth of matching striae are calculated for each shift in position. The maximum number of consecutively matched striae is also counted for each shift in position. From the fluctuating pattern of these calculated parameters, the reliability of a positive conclusion can be calculated. Uchiyama calculated the significance level of his positive conclusions by evaluating a certain number of indented lines that matched to a specified ratio.

The algorithms used by both Drugfire and IBIS are proprietary and therefore not available for review. It is known that the computer algorithm does not count 'matching striae', but reviews the whole image, and searches for similar patterns of markings between the two bullets. The performance of the IBIS Brasscatcher to acquire and correlate breech face and firing pin impressions on fired cartridge casings has been studied.[133] Pairs of casings from over 200 semiautomatic pistols, representing 25, 380, 9mm, and 45 calibre's, were entered into the IBIS system for correlation without prior microscopic screening. The 'correct' twin cartridge casing was determined to be in the top position of the ranked score up to 78% of the time and in one of the top five positions up to 93% of the time. The images were evaluated using visual subjective judgement and it was found that cartridge casings, judged to be 'good' and 'fair' in quality, constituted the bulk of 'top position' matches. It was also noted, however, that a number of 'poor' quality images were found in the 'top position' as well.

The directors of the ATF and the FBI have met with the Attorney General, and signed a memorandum of understanding (MOU) to create a unified ballistics evidence system.[134] The FBI has decided to terminate its Drugfire program, while ATF will assume overall responsibility for all current and future system sites, and the FBI will take on the task of establishing and maintaining a high-speed, secure communications network. The single, unified system will be known as the National Integrated Ballistics Identification Network (NIBIN).

Currently there are a number of automated systems working with different image acquisition systems and with proprietary search algorithms. The three most significant for bullet examination are IBIS, which is currently in use in nine different countries including the USA, ALIS, which has been developed to operational standard but is not currently used, and SciClops. SciClops represents an emerging technology that, in contrast to IBIS and ALIS, gives a three-dimensional image; there is a proposal to integrate this into the IBIS. It was decided to compare the performance of these three systems in the 10 consecutively rifled barrel test with that of human examiners; such a test has never been carried out. The significance of this test is discussed in Chapter 3. Only one of these three systems, IBIS, has the ability to examine cartridge cases. The 617 cartridge cases were examined, using IBIS, to test the ability of the system to handle significant numbers of similar cases; this represents the most comprehensive trial to date.

EXPERIMENTAL DESIGN

The experiments were undertaken to answer some of the following questions:

> To determine if ballistics imaging systems such as ALIS, IBIS, and SciClops have the ability to correctly associate known and unknown bullets

obtained by test firing 10 consecutively rifled pistol barrels as described in Chapter 3.

To determine if the IBIS Unit, has the ability to correctly associate test fired cartridge cases to each other and to the exclusion of like-type cartridge casings obtained by test firing 617 Glock semiautomatic pistols as explained in Chapter 4. The instrument had never been tasked with evaluating this many like-type cartridge casing in a single experiment.[135]

MATERIALS AND METHODS

Ten-barrel tests sets, see Chapter 3, were sent to the following:

Dr. Benjamin Bachrach, Senior Research Scientist, Intelligent Automation, Incorporated (IAI), developers and manufacturers of the SciClops, for examination;

Mr. Tsuneo Uchiyama, Head of the 2nd Mechanical Section, National Research Institute of Police Science, for examination using ALIS,

Mr. Robert M. Thompson, Senior Forensic Scientist, ATF Forensic Science Laboratory - San Francisco, for examination using IBIS.

Each participant was requested to evaluate the known and unknown bullets, using their system, and then to complete the answer sheet provided with each set. There were also requested to pass any comments as they saw fit.

The 617 cartridge casings, discussed in Chapter 4, were entered into the Data Acquisition Station (DAS) portion of the IBIS at the Indianapolis-Marion County Forensic Services Agency. A SAS/DAS Unit, which serves as our local 'hub' unit and is located at the Indiana State Police (ISP) Laboratory in Indianapolis, Indiana, carried out the correlation. The images were also electronically forwarded for correlation by the SAS Unit operated by Forensic Technology, Incorporated (FTI) in Canada.

RESULTS

SciClops System

The SciClops System correctly identified the 20 known bullets to each other and the 15 unknown bullets to the known bullets. In his report, Bachrach provides a preliminary evaluation of his system and states (in part): "The Indianapolis-Marion County Forensic Laboratory, has developed a firearms examiner evaluation consisting of bullets fired by 10 guns of the same model (9mm P85 Ruger Pistol). The barrels of these guns are not only of the same model, but they were consecutively manufactured, making them as similar as possible to each other. As part of this evaluation, the examiner is provided with one pair of control bullets from each barrel (totalling 20 bullets), and 15 questioned bullets. The examiner is asked to identify the gun (barrel) through which the 15 questioned bullets were fired by comparing them with the control bullets. Intelligent Automation, Inc. requested a set of these bullets and acquired their data using the SciClops system. The SciClops system was able to match all 15 questioned bullets to their corresponding barrels without difficulty"[136].

Automated Land Identification System (ALIS)

The ALIS System correctly identified the 15 unknown bullets to the 20 known bullets in the test set provided for evaluation. There were no supplementary comments.

Integrated Ballistics Identification System (IBIS)- 10 Barrel Test

The IBIS System correctly identified the 15 unknown bullets to the 20 known bullets in the test set provided. Thompson commented: "I essentially found the same barrels when compared with an additional 2,067 9mm Luger calibre bullets in the database. I was using the newly installed version 3.2 'Bulletproof' software for this evaluation". He states: "These identification were not verified by microscopic comparison at this stage, but the images look very good. We do not call a match based on IBIS alone, it has to be confirmed microscopically. Typically we use the IBIS after the examinations for additional potential 'links'. We also evaluated the same set with the previous 2.1 software against 1,909 9mm Luger calibre bullets with the same association as mentioned with the 3.2 software. We are using this set with another casing set to test for any increase in performance in the two versions of Bulletproof and Brasscatcher. The results will be reported separately".[137]

Integrated Ballistics Identification System (IBIS)- 617 Cartridge Casings

The IBIS System correlated the 617 cartridge casings and intercompared each against the other casings without any incorrect correlation.

DISCUSSION

Both known and unknown bullets, obtained by test-firing ten consecutively rifled barrels, were analysed using SciClops, ALIS, and IBIS automated ballistics imaging system. The three systems were capable of correctly identifying the 15 unknown bullets to the 20 known bullets – 2 sets of 10 each. The imaging systems, evaluating consecutively rifled barrels, were able to correctly associate the unknown bullets to the known bullets. To odds of achieving this assignment by chance are 1 in 10^{15} and can only mean that the systems can both detect and recognise characteristics features on the surface of fired bullets.

Cartridge casings, obtained by test firing 617 Glock pistols, were entered into an IBIS Unit for analysis for intercomparison. The IBIS computer intercompared the cartridge casings to each other during an overnight evaluation for a total of 380,689 comparisons. In the experiment, discussed in Chapter 4, the author utilised conventional comparison microscopy to only evaluate cartridge cases number 1 against casings 2 through 617, with no additional intercomparisons. These comparisons required an average of 10 minutes per cartridge case, for a total of over 102 hours. Assuming that an examiner worked on this experiment for 8 hours per day, that would still require over 2 ½ weeks of full time activity. The time required to attempt intercomparison between each of the casings, to each other, would require several months for a full time firearm's examiner. Data entry of the casings into IBIS required approximately 10 minutes per casing or approximately the same time as required to evaluate casings 1 to 2, and so forth. However once the data is entered it can be rapidly compared to all samples in the database and is available for rapid comparison in all subsequent cases. If this were done manually the case would need to be re-examined on each subsequent occasion taking considerably longer.

CONCLUSIONS

While the time required entering a volume of fired casings appears lengthy; the IBIS system provides the technology to make a large number of comparisons in a comparatively short period of time. Rapid comparison is essential if large 'open-case' files are to be searched for intelligence purposes. Currently the three automated systems tested here merely give the examiner a short list of candidates for examination; they do not decide whether or not the suspect cartridge component matches any on record on file in the 'open-case' file. With continued improvement of the systems the whole comparison process may become fully automated. Moran writes: "As in any automated forensic identification' system, the public mistakenly believes that identifications are made solely by the "computer". In fact the system is merely a screening tool to provide the examiner with a manageable number of suggested comparisons with the best chance of a positive association. The power of the systems is in substantially reducing search time which would otherwise make manual systems impractical with large data bases".[138] Goddard's concept is becoming reality.

CONCLUSIONS

Research was conducted, and published, to evaluate the potential requirement for forensic science laboratories to maintain weapons reference collections. It was determined that the majority of forensic laboratories that responded to the survey maintain a collection. The reported requirement for the collections contrasted markedly with the apparent infrequent use of the collections by laboratory examiners. Subsequent to the initial research, additional information concerning the actual use of collections was solicited, and it was determined that extensive uses were being made of the collections – the uses simply weren't being recorded. The use of the collections, especially for repairs and research, was evident and while examiners were prepared to accept photographs, and other representations to augment the collection; they rejected the idea of discarding the collections. There didn't appear to be any obvious upper limit to the collections as even those laboratories were very large collections tended to borrow selected firearms from time to time. Composition of the collection varied with both the catchement area and the willingness of various officials to release firearms to the laboratory for their collection. In many laboratories, the desire of the examiner is certainly one key to increasing the collection's size, as an example, in the authors' laboratory, we have determined that our collection needed to be increased. When the laboratory was formed 15 years ago, the collection was zero weapons. Today the collection has some 1,800 firearms with space in the vault for some additional 2,500 firearms. Sojat, in discussing firearms standards, states "...the ideal solution would be a collection of weapons representative of all types commonly used in criminal behaviour".

A research study was conducted to expand on a more limited study conducted by Brundage. Sets of fired bullets, obtained by test firing 10 consecutively rifled barrels in a Ruger P-85 pistol, were labelled either known or unknown and provided to firearms examiners internationally. This procedure provided an examiner with best possible known 'non-match' as the bullets had been fired from barrels sequentially manufactured, using the same broaching tool. To date, some 201 examiners have completed the experiment and provided their answers, which contained no errors. Of the participants responding, they examined a total of 3,015 unknown bullets against the known bullets. Two examiners stated that they were unable to identify one of the unknown bullets. Their decision may be based on their comfort level, damage to the specific bullets, etc., and doesn't represent an error. Their evaluations could not be by chance which would mean that the characteristics were observable by each. Inasmuch as a large number of examiners correctly associated the 'unknown' bullets to the 'known' bullets, this would indicate that the ability to correctly associate fired component evidence is not esoteric; but rather an examination that is generally present in the firearms examiner community. This test represents excellent association of fired bullets from consecutively rifled barrels, where the bullets were in reasonably good condition.

Firearms examiners have routinely examined fired cartridge cases, and then associated them to firearms submitted as part of an investigation. Four cartridge casings were obtained by test firing some 617 Glock pistols and then microscopically evaluated to determine if an examiner could correctly associate each casing from the same firearm to itself; and disassociate the casings from the other 616 casings. It was possible to specifically identify each casing to itself and not the others.

A series of experiments were conducted to evaluate some automated digital imaging systems, using fired components described in Chapters 3 and 4. The studies were designed to evaluate the ability of the various systems, compare the results with those obtained by firearms examiners; and determine if the system could distinguish between the best known 'match' and 'non match' bullets fired from consecutively rifled barrels. Whilst it was determined that the time required for entry into an automated system is somewhat the same as an examiner performing a single examination of the same type, the ability of the system to rapidly evaluate large amounts of data are much faster. Additionally, an automated system can handle large data files and correctly identify fired components with no Type 2 errors. In most forensic organisations, inaccurate analysis of evidence is usually classified into two types – Type 1 errors and Type 2 errors. A 'Type 1' error indicates a misidentification while a 'Type 2' error indicates an incorrect exclusion. [139]

SUGGESTIONS FOR FUTURE WORK

Examiners, in general, have demonstrated their ability to successfully identify undamaged projectiles fired from consecutively rifled barrels. Inasmuch as no errors were reported in the consecutively rifled barrel experiment, one can't establish an error rate for the examination. It is understood, however, that examiners daily evaluate fired evidence bullets that are damaged or fragmented. Future research could be conducted that involve both damaged and fragmented bullets and potential error rates calculated.

The research could consist of bullets being test fired and specific land and groove impressions being mechanically removed to produce damaged bullets. For example, a 9mm calibre bullet, similar to the one in this study, could be 'manually damaged' so that the same three land and groove impressions were present for examination by the examiner. The manufacturer would microscopically evaluate the damaged bullets prior to distribution. As an alternative method, hollow point bullets could be test fired and portions of the fired bullet jackets used to provide the test materials. An alternative to actually damaging the projectiles would be to cover specific land and groove impressions with an opaque paint to simulate damage.

Additionally, research similar to this study, could also be undertaken with the introduction of one or more non-matching like-type bullets as 'unknowns' to further explore the error rate associated with this type of examination. It is suggested that the studies involving both damaged bullets and non-matching bullets could be combined to better test examiners and develop error rates.

The ability of some automated systems to critically evaluate large numbers of fired component evidence has been demonstrated. It is recommended that the systems be further evaluated to determine if the system is capable of correlating entered data against itself to preclude possible Type 1 and Type 2 errors as discussed above. These automated systems should also be used to evaluate damaged bullets and bullet fragments as mentioned above. Additionally, the damaged projectiles could be digitally imaged into the systems to determine the percentage of striations that are required for the system to 'identify' the projectile or fragment. The percentage of striations could then be compared against data obtained by examiners evaluating the same evidence using conventional comparison microscopy. For example, projectiles with opaque land and groove impressions would be entered into an automated system for correlation and also evaluated by a number of examiners using conventional comparison microscopy.

It is also recommended that additional 'criteria for identification' studies be conducted to provide answers to some of the issues brought forth by various current legal challenges such as Daubert, et al. These studies could include a variety of experiments utilising the test fired components previously mentioned in Chapters 3 and 4. For example, cartridge casings obtained by test firing the 617 Glock pistols could be entered into various automated systems after a portion of the firing pin impression was photographically or mechanically removed. The experiment could involve a series of mini-experiments where the striations on the firing pin were incrementally reduced, in increments of 5%, to determine the amount of data that would allow the system to correlate the casing to itself.

References

[1] Encyclopaedia of Forensic Science
D. Wielbo and Jay A. Siegel
Academic Press, New York: 2000.

[2] Handbook of Methods for the Restoration of Obliterated Serial Numbers
Treptow, R.
NASA Contract Report CR-135322, Washington: 1978.

[3] The History of Firearms Identification
James E. Hamby and James W. Thorpe
AFTE Journal, **31**, 1999, p. 266.

[4] On Death's Bloody Trail
Marriner, B.
St. Martin's Press, New York: 1991.

[5] The History of Firearms Identification
Berg, S.
International Association for Identification Newsletter, Raleigh: 1965, p. 3.

[6] A History of Firearms
Peterson, H.
Charles Scribner's Sons, New York: 1961.

[7] Op Cit. (Berg).

[8] Op Cit. (Berg).

[9] The Missile and the Weapon
Hall, A.
American Journal of Police Science, **2**, 1931, p. 311.

[10] A History of Firearms Identification
Goddard, C.
Chicago Police Journal, **13-13**, 1936, p. 27.

[11] Op Cit. (Berg)

[12] Fingerprinting Bullets – The Expert Witness
Stout, W.
The Saturday Evening Post (June 13 & 25 Issues), Indianapolis: 1925.

[13] A Historical Perspective of Firearms Reference Collections
James E. Hamby and James W. Thorpe
AFTE Journal, **31**, 1999, p. 291.

[14] U.S. Senate Document – Number 402
Volume 21-23, Washington: 1907.

[15] The Identification of Firearms and Forensic Ballistics
Burrard, G.
A.S. Barnes and Company, New York: 1962.

[16] Firearms Identification – Volumes I and II
Mathews, J.
Charles C. Thomas, Publisher, Springfield: 1962

[17] Firearms Identification – Volume III
Mathews, J.
Charles C. Thomas, Publishers, Springfield: 1973.

[18] Personal observations by the author.

[19] Les Fissures du Crane: Coups de Feu a Courte Distance
P. Chavigny and F. Gelma
Annales de Medicine Legale, **3**, 1921, p. 345.

[20] Dispersion of Bullet Energy in Relation to Wound Effects
Wilson, L.
The Military Surgeon, September 1921, Washington, DC

[21] Estimation of Shooting Distance from Deformation of the Recovered Bullet
Uri Ben-Tovim and Bernard Schecter
AFTE Journal, **25**, 1993, p. 31.

[22] Preliminary Evaluation of the Terminal Performance of the 5.7x28mm 23 grain FMJ Bullet fired by the New FN P-90, Using 10% Ordnance Gelatin as a Tissue Simulant
Roberts, G.
AFTE Journal, **30**, 1998, p. 326.

[23] Terminal Performance of 9mm 147gr Jacketed Hollow Point Bullets Fired from the HK MP-5, using 10% Ordnance Gelatin as a Tissue Simulant
Roberts, G.
AFTE Journal, **30**, 1998, p. 330.

[24] The Other Mr. Churchill
Hastings, M.
Dodd, Mead and Company, London: 1965.

[25] Firearms Investigation, Identification and Evidence
Julian S. Hatcher, Frank J. Jury and Jac Weller
The Stackpole Company, Harrisburg: 1957.

[26] Op Cit. (Burrard)

[27] Textbook of Firearms Investigation, Identification and Evidence
Hatcher, J.
Small-Arms Publishing Company, Plantersville: 1935.

[28] The Identification of Firearms
Jack D. Gunther and Charles O. Gunther
John Wiley and Sons, Inc., New York: 1935.

[29] Firearms, the Law and Forensic Ballistics
Warlow, T.
Taylor and Francis, Ltd., London: 1996.

[30] Handbook of Firearms and Ballistics
Heard, B.
John Wiley and Sons, London: 1997.

[31] Personal correspondence in the author's files.

[32] The Re-Examination of Firearms Evidence in the Robert F. Kennedy Assassination
Garland, P.
AFTE Journal, **8**, 1976, p.5.

[33] Personal participation by the author.

[34] Firearm and Toolmark Identification – Meeting the Daubert Challenge
Richard A. Grzybowski and John E. Murdock
AFTE Journal, **30**, 1998, p. 3.

[35] Criteria for Identification of Toolmarks
Jerry Miller and Michael McLean
AFTE Journal, **30**, 1998, p. 15.

[36] Striae Reproducibility on Sectional Cuts of One Thompson Contender Barrel
Fred Tulleners and Mike Giusto
AFTE Journal, **30**, 1998, p. 62.

[37] The Language of Toolmarks
Collins, J.
AFTE Journal, **30**, 1998, p. 82.

[38] Consecutive Matching Striation Criteria: A General Critique
Bunch, S.
Jnl of Forensic Sciences, **45**, 2000, p. 955.

[39] Personal observations of the author.

[40] Op. Cit. (Goddard)

[41] Scientific Identification of Firearms and Bullets
Goddard, C.
Jnl of Criminal Law, Criminology, and Police Science, **17**, 1926.

[42] Op. Cit. (Churchill)

[43] Forensic Chemistry and Scientific Criminal Investigation
Lucas, A.
Edward Arnold & Company, London: 1931.

[44] Scientific Crime Detection Laboratories in Europe
Goddard, C.
American Journal of Police Science, **1**, 1930. p. 27.

[45] Firearm and Bullet Identification
Lewis, T. N.
The National Police Officer, April 1935.

[46] The FBI Laboratory
FBI Pamphlet 0-370-260
US Government Printing Office, Washington:1982

[47] Personal communication by the author.

[48] ATF Stores 4,000 Firearms
AFTE Journal, **11**, 1979, p.23.

[49] Personal communication by the author.

[50] Firearms Exemplar Collection
Christansen, R.
AFTE Journal, **17**, 1985, p. 115.

[51] Science in Crime Detection
Morland, N.
Emerson Books Incorporated, New York: 1960.

[52] Firearms as Evidence
Goddard, C.
American Jnl of Police Science, **1**, 1930, p. 24.

[53] Op. Cit. (Gunther & Gunther)

[54] Op. Cit. (Hatcher Jury & Weller)

[55] Organisation, Study and Use of Fired Standards
Sojat, J.
Jnl of Forensic Sciences, **10**, 1965, p.68.

[56] Firearms
McCafferty, J.
Jnl of the Forensic Science Society, **5**, 1965, p. 12.

[57] The Qualifications of a Ballistics Expert
Crossman, E.
AFTE Journal, **17**, 1985, p. 119.

[58] What the Bullet Tells
Pollard, H.
AFTE Journal, **19**, 1987, p. 289.

[59] The Crime Laboratory – Organisation and Operation
Paul L. Kirk and Lowell W. Bradford
Charles C. Thomas Publishers, Springfield: 1965.

[60] Op. Cit. (Matthews)

[61] Computerised Reference Firearms Collections
Elizabeth Gillis and Carlos Rosati
AFTE Journal, **27**, 1995, p. 17.

[62] Gunsights Out in the Field
Forensic Technology News, Fall 2000, p. 2.

[63] Op. Cit. (Warlow)

[64] Op. Cit. (Heard)

[65] Firearms Reference Collections – Their Size, Composition and Use
James E. Hamby and James W. Thorpe
Jnl of Forensic Sciences, **42**, 1997: p. 461.

[66] Personal communications by the author.

[67] The Identification of Consecutively Rifled Gun Barrels
Brundage, D.
AFTE Journal, **30**, 1998, p. 112.

[68] The Marks of Cain
Thorwald, J.
Thames and Hudson, London: 1965.

[67] Glossary of the Association of Firearm and Toolmark Examiners, 3d Ed.
AFTE Standardisation Committee
Available Business Forms, Chicago: 1994

[70] The Modern Gunsmith – Two Volumes In One
Howe, J.
Bonanza Books, New York: 1982.

[71] Encyclopaedia of American Gun Design and Performance
Wallack, L.
Winchester Press, New Haven: 1983.

[72] Op. Cit. (Mathews)

[73] Op. Cit. (AFTE Glossary)

[74] Op. Cit. (AFTE Glossary)

[75] Op. Cit. (AFTE Glossary)

[76] Op. Cit. (AFTE Glossary)

[77] Op. Cit. (AFTE Glossary)

[78] Op. Cit. (AFTE Glossary)

[79] Op. Cit. (AFTE Glossary)

[80] Comparison of 900 Consecutively Fired Bullets and Cartridge Cases from a .455 Calibre S & W Revolver
Kirby, S.
AFTE Journal, **15**, 1983, p.113.

[81] Identification of Projectiles
Hamby, J.
AFTE Journal, **6**, 1974, p. 22.

[82] Comparison of 5000 Consecutively Fired Bullets and Cartridge Cases From a 45 calibre M1911A1 Pistol
Yoshimitsu Ogihara, et al.
AFTE Journal, **15**, 1983, p.127.

[83] Calibre Raven Pistol Comparison of 501 Consecutively Fired Bullets and Cartridge Cases from a 25 Semi-Automatic Pistol
Robert J. Shem and Peter P. Striupaitis
AFTE Journal, **15**, 1983, p. 109.

[84] Comparison of Four Thousand Consecutively Fired, Steel Jacketed Bullets from a 9X18mm Makarov Pistol
Doelling, B.
Jnl of Forensic Sciences (In Press)

[85] Op. Cit. (Burrard)

[86] Consecutive Revolver Barrels
Lutz, M.
AFTE Newsletter, **9**, 1970, p. 24.

[87] The Effects of Crowning on Gun Barrel Individuality
Murdock, J.
Jnl of Forensic Science Society, **12**, 1972, p. 305.

[88] A General Discussion of Gun Barrel Individuality and an Empirical Assessment of the Individuality of Consecutively Rifled 22 Calibre Rifles
Murdock, J.
AFTE Journal, **17**, 1985, p. 64.

[89] Bullet Markings from Consecutively Rifled Shilen DGA Barrels
Hall, E.
AFTE Journal, **15**, 1983, p. 33.

[90] Comparison of Three Individual Barrels Produced from One Button Rifled Barrel Blank
Matty, W.
AFTE Journal, **17**, 1985, p. 64.

[91] How to Refute the Experts'
Adler, M.
AFTE Newsletter, **20**, 1972, p. 23.

[92] The Myth of Bullet Matching
Fox, R.
Forensic Science, Civil and Criminal Symposium, Eugene: November 1987

[93] The Case against Daubert: The New Scientific Evidence "Standard" and the Standards of Several States
Thomas L. Bohan and Erik J. Heels
Jnl of Forensic Sciences, **40**, 1995, p. 1030.

[94] Op. Cit. (Brundage)

[95] Availability of Test Fired Bullets from 10 Consecutively Rifled Barrels
Hamby, J.
AFTE Journal, **32**, Winter 2000, p. 58

[96] Report on Two Early Firearms Cases
Dougherty, P.
Jnl of Forensic Science, **14**, 1969, p. 453.

[97] The Guns of Brownsville
Garrison, D.
AFTE Journal, **18**, 1986, p. 65.

[98] Op. Cit. (Smith)

[99] Op. Cit. (Burrard)

[100] Op. Cit. (Burrard)

[101] Op. Cit. (Morland)

[102] The Scientific Investigation of Crime
Nicholas, L.
Butterworth & Company, London, 1956.

[103] Op. Cit. (Nicholas)

[104] Personal communication by the author.

[105] The "Hammer – Murderer"
Grooß, K.
AFTE Journal, **27**, 1995, p. 27.

[106] The Case against Daubert: The New Scientific Evidence "Standard"
Thomas L. Bohan and Erik J. Heels
Journal of Forensic Sciences, **40**, 1995, p. 1030.

[107] A History of Firearms Identification
Goddard, C.
Chicago Police Journal, **13-13**, Chicago: 1936.

[108] Operation "On-Target" - A Multiagency Approach to the Solution of Problems In the Field of Forensic Science
Eric W. Witzig and George R. Wilson
AFTE Journal, **25**, 1993, p. 246.

[109] Manual and Automated Bullet and Cartridge Case Comparison Systems
Moran, B.
AFTE Journal, **29**, 1977, p. 55.

[110] Op. Cit. (AFTE Glossary)

[111] Personal observations by the author.

[112] An Introduction to Toolmarks, Firearms and the Striagraph
Davis, J.
Charles C. Thomas, Publishers, Springfield: 1958.

[113] A Computer-Based Weapons Identification System
Scott, B.
Engineering New, June 1964, p. 291.

[114] New System for Toolmark Identification: Electronic Imaging and Comparison
Warren, G.
AFTE Journal, **23**, 1991, p. 990.

[115] Automatic Comparison of Land Marks
Uchiyama, T.
AFTE Journal, **20**, 1988, p. 252.

[116] The FBI Laboratory's Drugfire Program
John H. Dillon and Robert W. Sibert
FBI Law Enforcement Bulletin, December 1989, p. 25.

[117] The Microchip and the Bullet: A Vision of the Future
Barrett, M.
AFTE Journal, **23**, 1991, p. 876.

[118] Computer Identification of Bullets
Gardner, G.
AFTE Journal, **11**, 1979, p. 26.

[119] Examination of Firing Pin Impressions By Scanning Electron Microscopy
C. A. Grove, G. Judd and R. Horn
Jnl of Forensic Science, **17**, 1972, p. 645.

[120] Evaluation of SEM Potential in the Examination of Shotgun and Rifle Firing Pin Impressions
C. A. Grove, G. Judd and R. Horn
Jnl of Forensic Science, **19**, 1974, p: 441.

[121] Forensic Applications of the Scanning Electron Microscope
E. J. Korda, H. L. MacDonell and J. P. William
Jnl of Criminal Law, Criminology and Police Science, **61**, 1970, p. 453.

[122] Firearms Examination By Scanning Electron Microscopy
Mary-Jacque Mann, Edgard O. Espinoza and Michael Scanlon
AFTE Journal, **24**, 1992, p. 294.

[123] A New Approach to Firearms Examination
Warner, E.
AFTE Newsletter, **8**, 1970, p. 20.

[124] Surface Topology of Bullet Striations: An Innovating Technique
Jan De Kinder, Pascal Prévot, Marc Pirlot and Bart Nys
AFTE Journal, **30**, 1998, p. 294.

[125] Computer Identification of Bullets
Gardner, G.
AFTE Journal, **11**, 1979, p. 26.

[126] Visualisation by Confocal Microscopy of Traces on Bullets and Cartridge Cases
M. S. Bonfanti and R. I. Ghauharali
Jnl of the Forensic Science Society, **40**, 2000, p. 241.

[127] SciClops™: A 3D-Based Ballistics Analysis System
Bachrach, B.
Jnl of Forensic Science (In press)

[128] A Study of Idealised Striated Marks and their Comparison Using Models
Brackett, J.
Jnl of the Forensic Science Society, **10**, 1970, p. 27.

[129] Studies of Models and Marks Generated by Random Processes
Deinet, W.
Jnl of Forensic Sciences, **26**, 1981, p. 35.

[130] Methods Applied to the Comparison of Class and Individual Characteristics in Firearms and Toolmark Identification
Biasotti, A.
AFTE Journal, **12**, 1980, p. 81.

[131] A Statistical Study of the Individual Characteristics of Fired Bullets
Biasotti, A.
Jnl of Forensic Science, **4**, 1959, p. 34.

[132] Automated Landmark Identification System
Uchiyama, T.
AFTE Journal, **25**, 1993, p. 172.

[133] Computerised Image Analysis for Firearms Identification (IBIS)
Robert M. Thompson and Michael Desrosiers
AFTE Journal, **28**, 1996, p. 194.

[134] Fingerprinting Ballistics Evidence
Strandbery, K.
Law Enforcement Technology, May 2000, p.58.

[135] Personal communications by the author.

[136] Ballistic Matching Using 3D Images of Bullets and Cartridge Cases
Bachrach, B.
Progress Report – Phase II – Intelligent Automation, Inc., Rockville: 2000.

[137] Personal communications by the author.

[138] Manual and Automated Bullet and Cartridge Case Comparison Systems
Moran, B.
AFTE Journal, **29**, 1977, p. 55.

[139] Personal observations by the author.

APPENDIX 4

Chisquare Calculation for Reference Collection Composition

Revised Data Set

Type	Urban	Mixed	Rural	Total
Rifles	2436	15181	25	17642
Shotguns	1250	8978	13	10241
Pistols	5983	29070	50	35103
Revolvers	6282	23152	35	29469
Auto	264	3108	2	3374
Total	16215	79489	125	95829

Fraction of Total

	Urban	Mixed	Rural	Total
Rifles	0.03115	0.15271	0.00024	0.1841
Shotguns	0.01808	0.08865	0.00014	0.10687
Pistols	0.06198	0.30385	0.00048	0.36631
Revolvers	0.05203	0.25508	0.0004	0.30752
Auto	0.00596	0.02921	4.6E-05	0.03521
Total	0.16921	0.82949	0.0013	1

Expected No. in Each Cell

	Urban	Mixed	Rural	Total
Rifles	2985.16	14633.8	23.0123	17642
Shotguns	1732.86	8494.79	13.3584	10241
Pistols	5939.7	29117.5	45.7886	35103
Revolvers	4986.38	24444.2	38.4396	29469
Auto	570.907	2798.69	4.40107	3374
Total	16215	79489	125	95829

Chisquare

	Urban	Mixed	Rural	Total
Rifles	101.026	20.4594	0.17168	121.657
Shotguns	134.546	27.4869	0.00962	162.043
Pistols	0.31571	0.07754	0.38734	0.78059
Revolvers	336.643	68.3079	0.30777	405.259
Auto	164.986	34.1843	1.30994	200.48
Total	737.517	150.516	2.18635	890.219

APPENDIX 5

1	AMM285US	17	207	AMS010US	19	413	AMM626US	17
2	AMS197US	19	208	AMS146US	19	414	AMM349US	17
3	AMM693US	17	209	AMS167US	19	415	AMM448US	17
4	AMM690US	17	210	AMS283US	19	416	AMM639US	17
5	AMM364US	17	211	AMS151US	19	417	AMM315US	17
6	AMM598US	17	212	AMS043US	19	418	AMM075US	17
7	AMM741US	17	213	AMS191US	19	419	AMM734US	17
8	AMS173US	19	214	AMS176US	19	420	AMM410US	17
9	AMM430US	17	215	AMM130US	17	421	AMM767US	17
10	AMM275US	17	216	AMM405US	17	422	AMM245US	17
11	AMM234US	17	217	AMM445US	17	423	AMM656US	17
12	AMM382US	17	218	AMM583US	17	424	AMM211US	17
13	AMS260US	19	219	AMM462US	17	425	AMM020US	17
14	AMM610US	17	220	AMM188US	17	426	AMM476US	17
15	AMM654US	17	221	AMM542US	17	427	AMS074US	19
16	AMS264US	19	222	AMM185US	17	428	AMS149US	19
17	AMM283US	17	223	AMM586US	17	429	AMS171US	19
18	AMM447US	17	224	AMM449US	17	430	AMS187US	19
19	AMS172US	19	225	AMM784US	17	431	AMS223US	19
20	AMM318US	17	226	AMM157US	17	432	AMM165US	17
21	AMM415US	17	227	AMM483US	17	433	AMM531US	17
22	AMM012US	17	228	AMM094US	17	434	AMM216US	17
23	AMM495US	17	229	AMM651US	17	435	AMM708US	17

24	AMM614US	17	230	AMM414US	17	436	AMM210US	17
25	AM M107 US	17	231	AMM346US	17	437	AMM590US	17
26	AM M710 US	17	232	AMM227US	17	438	AMM408US	17
27	AM M243 US	17	233	AMM172US	17	439	AMM562US	17
28	AM M360 US	17	234	AMM552US	17	440	AMM116US	17
29	AM S181 US	19	235	AMM669US	17	441	AMM646US	17
30	AMS201US	19	236	AMM440US	17	442	AMM219US	17
31	AMM581US	17	237	AMM223US	17	443	AMM469US	17
32	AMM643US	17	238	AMM518US	17	444	AMM256US	17
33	AMS130US	19	239	AMM308US	17	445	AMM592US	17
34	AMM224US	17	240	AMM782US	17	446	AMM794US	17
35	AMM151US	17	241	AMM607US	17	447	AMM374US	17
36	AMM551US	17	242	AMM337US	17	448	AMM317US	17
37	AMM703US	17	243	AMM608US	17	449	AMM398US	17
38	AMM739US	17	244	AMS068US	19	450	AMS038US	19
39	AMM505US	17	245	AMS055US	19	451	AMM378US	17
40	AMS255US	19	246	AMS095US	19	452	AMM220US	17
41	AMS269US	19	247	AMS038US	19	453	AMM102US	17
42	AMS119US	19	248	AMS067US	19	454	AMM001US	17
43	AMS141US	19	249	AMS140US	19	455	AMM704US	17
44	AMM804US	17	250	AMS210US	19	456	AMM064US	17
45	AMS096US	19	251	AMS013US	19	457	AMM709US	17
46	AMS114US	19	252	AMS261US	19	458	AMM745US	17
47	AMM490US	17	253	AMS183US	19	459	AMM557US	17

48	AMM724US	17	254	AMM290US	17	460	AMM476US	17
49	AMS251US	19	255	AMM695US	17	461	AMM257US	17
50	AMM520US	17	256	AMM221US	17	462	AMM399US	17
51	AMS188US	19	257	AMM595US	17	463	AMM087US	17
52	AMS023US	19	258	AMM625US	17	464	AMM729US	17
53	AMM101US	17	259	AMM501US	17	465	AMM141US	17
54	AMM263US	17	260	AMM151US	17	466	AMM334US	17
55	AKS049US	19	261	AMM010US	17	467	AMM128US	17
56	AME012US	17	262	AMM602US	17	468	AMM342US	17
57	BAM637US	17	263	AMM628US	17	469	AMM412US	17
58	AMA608US	17	264	AMM302US	17	470	AMM736US	17
59	AMS056US	19	265	AMM561US	17	471	AMM696US	17
60	AMS267US	19	266	AMM718US	17	472	AMM732US	17
61	AMS118US	19	267	AMM026US	17	473	AMM110US	17
62	AMS070US	19	268	AMM209US	17	474	AMM159US	17
63	AKM260US	19	269	AMM559US	17	475	AMM777US	17
64	AME020US	17	270	AMM601US	17	476	AMM158US	19
65	AMS234US	19	271	AMM597US	17	477	AMS003US	19
66	AMM616US	17	272	AMM341US	17	478	AMS243US	19
67	AMM384US	17	273	AMM170US	17	479	AMS092US	19
68	AMM402US	17	274	AMM083US	17	480	AMS175US	19
69	AMM261US	17	275	AMM008US	17	481	AMS135US	19
70	AMS052US	19	276	AMM537US	17	482	AMS207US	19
71	AMS134US	19	277	AMM200US	17	483	AMS027US	19

72	AMS257US	19	278	AMM498US	17	484	AMM800US	17
73	AMM390US	17	279	AMM611US	17	485	AMM644US	17
74	AMS247US	19	280	AMM205US	17	486	AMM217US	17
75	AMS053US	19	281	AMM471US	17	487	AMM514US	17
76	AMS054US	19	282	AMM674US	17	488	AMM522US	17
77	AMS139US	19	283	AMS252US	19	489	AMM030US	17
78	AMS137US	19	284	AMS001US	19	490	AMM373US	17
79	AMM347US	17	285	AMS117US	19	491	AMM321US	17
80	AMS029US	19	286	AMS132US	19	492	AMM152US	17
81	AMS168US	19	287	AMS068US	19	493	AMM146US	17
82	AMS037US	19	288	AMS067US	19	494	AMM683US	17
83	AMS256US	19	289	AMS022US	19	495	AMM108US	17
84	AMS236US	19	290	AMS094US	19	496	AMM319US	17
85	AMS196US	19	291	AMM634US	17	497	AMM513US	17
86	AMS008US	19	292	AMM143US	17	498	AMM154US	17
87	AMS105US	19	293	AMM766US	17	499	AMM365US	17
88	AMM274US	17	294	AMM727US	17	500	AMM494US	17
89	AMM032US	17	295	AMM740US	17	501	AMM230US	17
90	AMM279US	17	296	AMM799US	17	502	AMM168US	17
91	AMS122US	19	297	AMM485US	17	503	AMM249US	17
92	AMS059US	19	298	AMM100US	17	504	AMM171US	17
93	AMS129US	19	299	AMM491US	17	505	AMM148US	17
94	AMS017US	19	300	AMM657US	17	506	AMM299US	17
95	AMM649 US	17	301	AMM134US	17	507	AMM450US	17

96	AMM246US	17	302	AMM612US	17	508	AMM343US	17
97	AKX707US	17	303	AMM480US	17	509	AMM328US	17
98	AMM403US	17	304	AMM269US	17	510	AMS005US	19
99	AMM555US	17	305	AMM090US	17	511	AMS044US	19
100	AMM470US	17	306	AMM296US	17	512	AMM138US	17
101	AMM721US	17	307	AMM773US	17	513	AMM534US	17
102	AMM521US	17	308	AMM028US	17	514	AMM407US	17
103	AMM624US	17	309	AMM569US	17	515	AMM451US	17
104	AMM164US	17	310	AMM705US	17	516	AMM436US	17
105	AMM065US	17	311	AMM755US	17	517	AMM339US	17
106	AMM553US	17	312	AMM155US	17	518	AMM139US	17
107	AMM204US	17	313	AMM444US	17	519	AMM663US	17
108	AMM786US	17	314	AMM122US	17	520	AMM589US	17
109	AMM580US	17	315	AMM231US	17	521	AMM386US	17
110	AMM089US	17	316	AMM282US	17	522	AMM509US	17
111	AMM429US	17	317	AMM353US	17	523	AMM367US	17
112	AMM232US	17	318	AMM752US	17	524	AMM619US	17
113	AMM792US	17	319	AMM661US	17	525	AMM675US	17
114	AMM103US	17	320	AMM468US	17	526	AMM539US	17
115	AMM215US	17	321	AMM150US	17	527	AMM189US	17
116	AMM163US	17	322	AMM413US	17	528	AMM579US	17
117	AMM622US	17	323	AMM280US	17	529	AMM131US	17
118	AMM787US	17	324	AMM207US	17	530	AMM697US	17
119	AMM218US	17	325	AMM304US	17	531	AMM731US	17

120	AMM370US	17	326	AMM352US	17	532	AMM298US	17
121	AMM306US	17	327	AMM228US	17	533	AMM617US	17
122	AKX708US	17	328	AMM142US	17	534	AMM481US	17
123	AMM191US	17	329	AMM345US	17	535	AMM512US	17
124	AMM653US	17	330	AMM046US	17	536	AMM576US	17
125	AMM167US	17	331	AMS093US	19	537	AMM460US	17
126	AMM085US	17	332	AMS226US	19	538	AMM754US	17
127	AMM037US	17	333	AMS161US	19	539	AMM571US	17
128	AMS237US	19	334	AMS011US	19	540	AMM600US	17
129	AMS041US	19	335	AMS035US	19	541	AMM338US	17
130	AMS162US	19	336	AMS032US	19	542	AMM570US	17
131	AMS021US	19	337	AMS235US	19	543	AMM720US	17
132	AMS048US	19	338	AMS031US	19	544	AMM428US	17
133	AMS110US	19	339	AMS186US	19	545	AMM785US	17
134	AMS212US	19	340	AMS222US	19	546	AMS219US	19
135	AMS107US	19	341	AMS250US	19	547	AMS177US	19
136	AMS262US	19	342	AMS016US	19	548	AMS203US	19
137	AMS285US	19	343	AMS190US	19	549	BEZ298US	17
138	AMS104US	19	344	AMS215US	19	550	AUV654US	17
139	AMS214US	19	345	AMS180US	19	551	AKX715US	17
140	AMS153US	19	346	AMS233US	19	552	BAA604US	17
141	AMM031US	17	347	AMS245US	19	553	BGR198US	17
142	AMM348US	17	348	AMS176US	19	554	AKE019US	17
143	AMM548US	17	349	AMM679US	17	555	AXA395US	17

144	AMM388US	17	350	AMM393US	17	556	AVX127US	17
145	AMM770US	17	351	AMM605US	17	557	AKX721US	17
146	AMM446US	17	352	AMM359US	17	558	AKX719US	17
147	AMM421US	17	353	AMM009US	17	559	AUA678US	17
148	AMM493US	17	354	AMM395US	17	560	AKE017US	17
149	AMM508US	17	355	AMM677US	17	561	BGS676US	17
150	AMM326US	17	356	AMM280US	17	562	AZF449US	17
151	AMM397US	17	357	AMM372US	17	563	AKE021US	17
152	AMM322US	17	358	AMM544US	17	564	AKX700US	17
153	AMM676US	17	359	AMM324US	17	565	AKE007US	17
154	AMM003US	17	360	AMM563US	17	566	AMM389US	17
155	AMM488US	17	361	AMM702US	17	567	AMM320US	17
156	AKE023US	17	362	AMM099US	17	568	AMM096US	17
157	AMM528US	17	363	AMM783US	17	569	AMM500US	17
158	AMM631US	17	364	AMM253US	17	570	AMM484US	17
159	AMM694US	17	365	AMM558US	17	571	AMM694US	17
160	AMM572US	17	366	AMM067US	17	572	AMM707US	17
161	AMS286US	19	367	AMM250US	17	573	AMM014US	17
162	AMS244US	19	368	AMM517US	17	574	AMM199US	17
163	AMS116US	19	369	AMM487US	17	575	AMM447US	17
164	AMM645US	17	370	AMM184US	17	576	AMM000US	17
165	AMM193US	17	371	AMM112US	17	577	AMM538US	17
166	AMM256US	17	372	AMM463US	17	578	AMM382US	17
167	AMM606US	17	373	AMM578US	17	579	AMM335US	17

168	AMM550US	17	374	AMM688US	17	580	AMM496US	17
169	AMM297US	17	375	AMM063US	17	581	AMM336US	17
170	AMM262US	17	376	AMM435US	17	582	AMM331US	17
171	AMM166US	17	377	AMM667US	17	583	AMM494US	17
172	AMM765US	17	378	AMM659US	17	584	AMM383US	17
173	AMM093US	17	379	AMM082US	17	585	AMM695US	17
174	AMM456US	17	380	AMM743US	17	586	AMM545US	17
175	AMM149US	17	381	AMS220US	19	587	AMM515US	17
176	AMM621US	17	382	AMS270US	19	588	AMM629US	17
177	AMS164US	19	383	AMM715US	17	589	AMM151US	17
178	AMS143US	19	384	AMM194US	17	590	AMM613US	17
179	AMS098US	19	385	AMM467US	17	591	AMM455US	17
180	AMS117US	19	386	AMM510US	17	592	AMM364US	17
181	AMS169US	19	387	AMM706US	17	593	AMM594US	17
182	AMS077US	19	388	AMM658US	17	594	AMM453US	17
183	AMS160US	19	389	AMM536US	17	595	AMM344US	17
184	AMS113US	19	390	AMM095US	17	596	AMM530US	17
185	AMS051US	19	391	AMM573US	17	597	AMM584US	17
186	AMM758US	17	392	AMM327US	17	598	AMM133US	17
187	AMM442US	17	393	AMM549US	17	599	AMM356US	17
188	AMM486US	17	394	AMM623US	17	600	AMM472US	17
189	AMM737US	17	395	AMM169US	17	601	AMM038US	17
190	AMM427US	17	396	AMM420US	17	602	AMM060US	17
191	AMM441US	17	397	AMM076US	17	603	AMS136US	19

192	AMM222US	17	398	AMM137US	17	604	AMS046US	19
193	AMM071US	17	399	AMS211US	19	605	AMS269US	19
194	AMM754US	17	400	AMS004US	19	606	AMS228US	19
195	AMM381US	17	401	AMS239US	19	607	AMS131US	19
196	AMM129US	17	402	AMS157US	19	608	AMS036US	19
197	AMM013US	17	403	AMS199US	19	609	AMS232US	19
198	AMM323US	17	404	AMS136US	19	610	AMS213US	19
199	AMM473US	17	405	AMS072US	19	611	AMS287US	19
200	AMM212US	17	406	AMS253US	19	612	AMS259US	19
201	AMM079US	17	407	AMS268US	19	613	AMS253US	19
202	AMS249US	19	408	AMS254US	19	614	AMS086US	19
203	AMS205US	19	409	AMM646US	17	615	AKX703US	17
204	AMS275US	19	410	AMM423US	17	616	AKE000US	17
205	AMS252US	19	411	AMM011US	17	617	AKE006US	17
206	AMS207US	19	412	AMM104US	17			