UTS UNIVERSITY OF TECHNOLOGY SYDNEY

On the effect of decomposition processes on fired bullet striae and post-mortem interval estimates.

by Matthew Scott Bolton

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Master of Science (Research)

under the supervision of Dr. Maiken Ueland and Dr. Scott Chadwick

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Certificate of Original Authorship

I, Matthew Bolton, declare that this thesis is submitted in fulfilment of the requirements for the award of Master of Science (Research), in the of Mathematical and Physical Sciences at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise referenced or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

This document has not been submitted for qualifications at any other academic institution.

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Table of Contents

List of Figures

List of Tables

Abbreviations

AFTE	Association of Firearm and Toolmark Examiners
ABS	Australian Bureau of Statistics
AFTER	Australian Facility for Taphonomic Experimental Research
AFP	Australian Federal Police
AFSAB	Australasian Forensic Science Assessment Body
BIS	Ballistics Investigation Section (New South Wales Police Force)
BoM	Bureau of Meteorology
FMJ	Full Metal Jacket
GEA	Groove Engraved Areas
LEA	Land Engraved Areas
LRN	Lead Round Nose
NSWPF	New South Wales Police Force
RAAF	Royal Australian Air Force (Base)
SWGGUN	Scientific Working Group for Firearms and Toolmarks
TASPOL	Tasmania Police Force
TBS	Total Body Score
UTS	University of Technology Sydney

Chapter 1: Introduction

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1.1 Introduction

A firearm is an assembly of a barrel and action from which a projectile (or projectiles) is propelled by products of propellant combustion and are a continued source of interest not only in the forensics field, but also in the media and public. In the New South Wales Firearms Act 1996, No.46 defines a firearm "*as a gun, or other weapon, that is (or at any time was) capable of propelling a projectile by means of an explosive, and includes a blank fire firearm, or an air gun, but does not include anything declared by the regulations not to be a firearm"*. According to the Australian Institute of Criminology, the National Homicide Monitoring Program report described 196 homicide incidents recorded by Australian state and territory police (except Australian Capital Territory) between 1 July 2017 and 30 June 2018 (Bricknell, 2020). In this same reporting period, a weapon was used in 159 homicide incidents (81%), of which, approximately 15% were committed with a firearm (Bricknell, 2020). For law enforcement officers the examination of ballistic related material recovered from scenes of crime is important to investigate, identify firearms, link offenders, and prosecute for these offences.

The Australian Bureau of Statistics (ABS) has previously reported that approximately 63% of all firearm deaths were attributed to rifles and 30% involved a shotgun; handgun related deaths were approximately 5% of the total (ABS, 2006). Firearm related crime may be relatively low compared to deaths from firearms due to self-harm or unintentional shootings, however, the investigation of these crimes is of importance to law enforcement agencies. When a firearm is used in the killing of another; the bullet used, when recovered, can provide valuable information to assist in the investigation of the offence.

1.2 Ammunition and Bullets

A single unit of ammunition (the cartridge) consists of a cartridge case designed to hold the propellant, primer or priming compound and bullet (du Preez, 2003). Cartridge naming conventions are generally established on combinations of bullet calibre, manufacturer, or type. Cartridges are described in terms of metric or imperial measurements; however, this can be interchangeable. An example is the .308 Winchester calibre cartridge; a cartridge that contains a bullet with an approximate diameter of .308 inches (7.8mm), originally designed and manufactured by the Winchester company (du Preez, 2003). Bullets are constructed in several

shapes from a variety of metals; however, lead and copper are the most common (Global Security, 2020), other bullet types are listed in Appendix 1.

Cartridge naming conventions are generally established on combinations of bullet calibre, which is a term used to designate the specific cartridge for which a firearm is chambered. In firearms, calibre is the approximate diameter of the circle formed by the tops of the lands of a rifled barrel, typically expressed in hundredths of an inch (.38 calibre) or millimetres (9mm calibre); in ammunition, calibre is a numerical term, included in a cartridge name to indicate the nominal bullet diameter, manufacturer, or type (Wilson, 2003). Cartridges are described in terms of metric or imperial measurements; however, this can be interchangeable.

When a cartridge is placed into a firearm and the primer is struck by the firing pin of the firearm, the bullet is expelled from the cartridge case due to the expanding gases created by the burning of the propellant. As the bullet accelerates through the bore of the firearm, internal grooves manufactured into the barrel (Figure 1.1.a: Simpson, 2020) impart spin on the bullet, which will provide gyroscopic stability to the projectile once it exits the muzzle. These machined areas of a rifled barrel create regions known as Land Engraved Areas (LEAs) and Groove Engraved Areas (GEAs) on the fired bullet (Figure 1.1.b: Doyle, 2019).

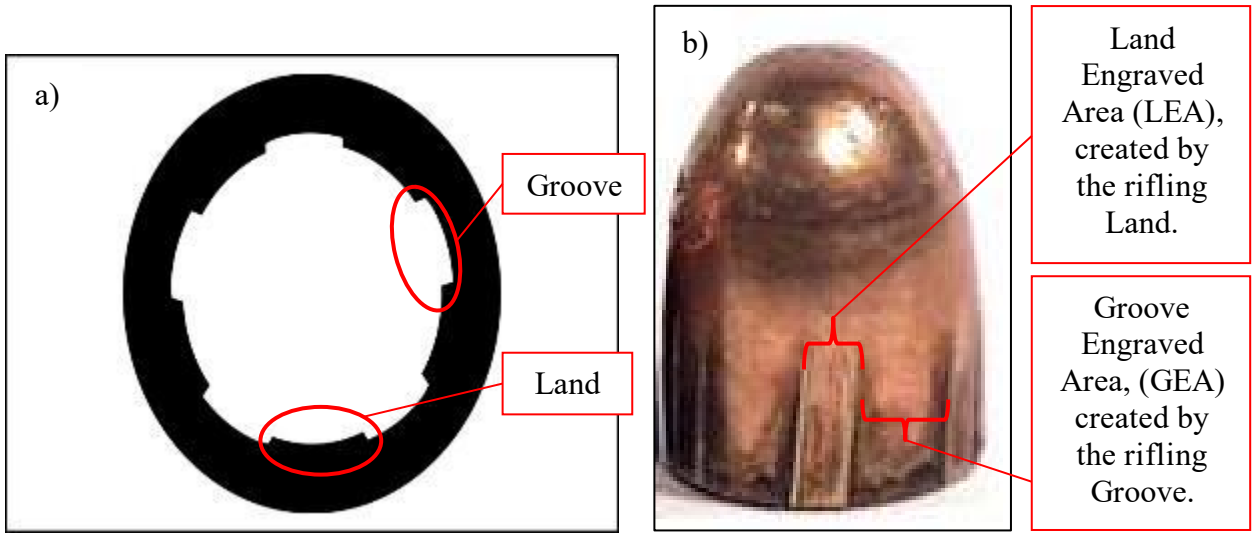


Figure 1.1(a) A diagram of a rifled barrel indicating lands and grooves, 1.1(b) Land engraved areas (LEAs) and Groove Engraved Areas (GEAs) on a fired bullet.

The burning or deflagration of the propellant generates a number of chemical elements and compounds that can be used in firearms examinations, described as Gunshot Residues (GSR). These GSR can be divided into inorganic (lead, barium, and antimony) primer-based residues (Noedel, 2009) and organic propellant base nitrite residues, generated by the combustion of nitrated cellulose constituents of the propellants (Haag, 2006), with soot and smoke also produced. Whilst these residues can assist the forensic examiner to determine if an individual was holding or

near a firearm at the time of discharge or provide information about the approximate (firearm) muzzle to target distance, these particles cannot be used to link a specific firearm to recovered ammunition components at a scene. It is at this point that toolmark identification and the use of comparison microscopy to compare the fired ammunition components becomes relevant to the investigation.

1.3 The Firearms and Toolmark Discipline – Microscopy

Toolmark identification is a branch of Forensic Science (Wilson, 2013). The underlying principle is when a 'harder' object, described as the tool, encounters a 'softer' work piece it imparts features of the tool on the work piece (SWGGUN, 2013). Toolmark identification can involve a multiple array of tools applied to a 'softer' surface. This may involve the jaws of a bolt-cutter applied to a padlock shackle, or a screwdriver used to jemmy a window open, imparting marks on the windowsill.

Forensic firearms examination is a subset of toolmark identification, in that the practitioner relies upon the toolmarks on the soft fired cartridge case and bullet surfaces imparted from the harder components of the firearm. The firearm components that leave these microscopic marks on the fired cartridge case are the firing pin (which begins the firing sequence), the extractor and ejector (which sequentially remove the fired cartridge case from the firearm) and the chamber and breech face (the portion of the firearm that houses the cartridge during the firing process). The machined areas of a rifled barrel create regions known as Land Engraved Areas (LEAs) and Groove Engraved Areas (GEAs) on the fired bullet and it is these areas which leave microscopic marks, or striations, that are used in the microscopic examination.

The imperfections are created during the manufacturing processes of drilling, reaming, rifling and finishing and from burrs due to the cutting and crowning at the muzzle of the barrel (Nichols, 2018). Striations or striae in the toolmark contexts are contour variations, generally microscopic, on the surface of an object caused by a combination of force and motion where the motion is approximately parallel to the plane being marked). These marks can contain class and/or individual characteristics (Wilson, 2013). These differ from impressed toolmarks, which are contour variations on the surface of an object caused by a combination of force and motion where the motion of the tool is approximately perpendicular to the plane being marked (Wilson, 2013).

Two general processes are employed to create the helical rifling within the barrel of the firearm. One method involves the removal of material from the barrel and the other forms the rifling by reshaping the metal around a harder object such as a mandrel, which is a metal rod or bar used as

a core around which a barrel can be forged, or shaped (Wilson, 2013) and does not involve the removal of any material (Nichols, 2018). Most manufacturing methods involved the transfer of rapidly changing or random marks onto work pieces, caused by tool wear, chip formation and corrosion (Nichols, 2018 and SWGGUN, 2013). Microscope marks on tools then may continue to change due to continued use and wear, resulting in the formation of these unique features, allowing firearms to be distinguished from another (Nichols, 2018). It is the imperfections within the barrel, as the bullet travels through it, which creates the striations on the surface of the bullet. The striations result from the initial manufacturing processes and the erosion and corrosion of the firearm during its lifetime.

The microscopic examination involves the use of a comparison microscope. This type of microscope is essentially two individual microscopes that are joined by an optical bridge (Wilson, 2013). The comparison microscope allows for the simultaneous examination of evidence that allows for the examiner to determine any sources of common origin. The examination of fired ammunition components is undertaken by placing one fired component (fired bullet or cartridge case) on one microscope stage and a second fired component (fired bullet or cartridge case) on the other microscope stage (Leica Microsystems, 2020). The examiner then views the components using the binocular eyepiece. The examiner will then use oblique and/or coaxial lighting and different magnification to highlight the areas of interest on the respective ammunition components. When an area of interest has been identified and the examiner believes that the marks correspond to a common origin, the examiner will move the components to determine if other areas of similarity exist on different parts of the components. This includes rotating fired bullets to other LEAs, to ascertain the level of correspondence in those additional areas or examining the ejector marks on two fired cartridge cases, if agreement is seen with their respective firing pin marks. The examiner will move the microscope stages (and therefore the ammunition components) to orientate the objects and bring any regions of interest into close proximity. If the examiner believes these areas to be significant enough to identify the components as having a common origin (i.e., from the same firearm), the view through the eyepieces is captured using the microscope's integral imaging software (Leica Microsystems, 2020). During the course of these examinations, it is important for the examiner to gain an appreciation of the marks available on both exhibit and test components and any carry-over of these marks in the test samples. This is completed by the examiner undertaking an examination of the test and exhibit fired ammunition components, prior to commencing any test to exhibit comparisons.

1.4 Interpretation of Forensic Firearms Evidence

1.4.1 Microscopic identification principles of forensic firearms examination

The random, microscopic irregularities transferred from the firearm to the cartridge case include, but are not limited to, the firing pin, extractor, ejector, and breechface. When a bullet is discharged from a firearm, the surface of the bullet is specifically analysed and comparisons made of those irregularities or striations contained within a bullet's LEA (Figure 1.2: Volburger *et al*., 2015). This allows for a barrel to be individually identified as having produced the marks on a bullet (SWGGUN, 2013). Microscopic marks on tools may continue to change due to continued use and wear, resulting in the formation of these features, allowing firearms to be distinguished from another (Nichols, 2018).

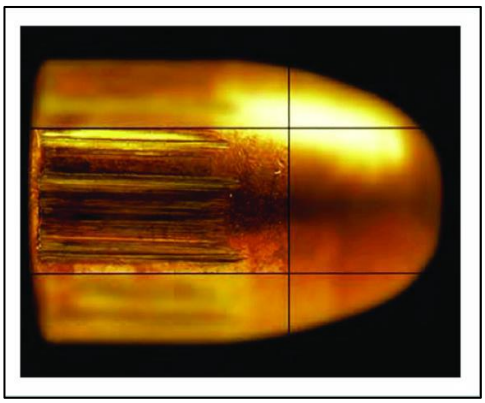


Figure 1.2: Example microscope image of fired bullet focussing on striations.

The grooves cut into a barrel are made by tools, such hook, or gang-broach cutters, that are harder than the barrel material (Nichols, 2018). These tools are used on consecutively manufactured barrels and being constructed of a harder material, they are more likely to pass any marks or imperfections on their cutting surface to more than one barrel. As cutting creates the only the grooves within the barrel, the lands are not affected by this carry-over from the cutting tool; in fact, the marks on the lands are left over from the drilling, reaming and finishing processes, that are random in nature (Nichols, 2018). Therefore, it is typically the LEAs which are examined as these areas retain the random marks from earlier manufacturing processes.

The examination of fired bullets in a forensic setting seeks to link the fired bullet to a specific firearm. This commences with comparing class characteristics, which are measurable features of a specimen which indicates a restricted group source (Wilson, 2013). They result from design factors and are determined prior to manufacture (Wilson, 2013) and includes the calibre, number and width of land and groove engraved areas and direction of the rifling twist on the fired bullet. Exhibit bullets are collected from a number of different scenarios and may be recovered from a shooting scene or from a deceased during a post-mortem examination. These exhibit bullets are

compared to other exhibit bullets, or those tests fired from exhibit firearms seized by law enforcement officers, handed in to the authorities or located by members of the public.

The class characteristics of the exhibit bullets and those of test fired bullets are compared as an initial step in the identification process. If the class characteristics do not agree, the exhibit firearm did not fire the recovered exhibit bullets. If the class characteristics of the exhibit and test fired bullets agree, the examiner then assesses the individual characteristics, which are marks produced by the random imperfections or irregularities of tool surfaces (Wilson, 2013). These random imperfections or irregularities are produced incidental to manufacture and/or caused by use, corrosion, or damage and are unique to that tool to the practical exclusion of all other tools (Wilson, 2013) and reported by the firearms examiner using a comparison microscope (SWGGUN, 2013) in accordance with the AFTE Theory of Identification (AFTE, 2020).

One of the main methods used to demonstrate the ability of firearms examiners to discriminate between different tools using comparison microscopy is by evaluating ammunition discharged in consecutively manufactured firearm components. Numerous studies have been conducted to evaluate the ability of firearms examiners to differentiate between ammunition components based upon the individual characteristics to identify a specific bullet to the barrel from which it was discharged. A study was conducted in which thirty examiners were required to examine multiple fired bullet controls and unknowns from ten consecutively manufactured self-loading pistol barrels (Brundage, 1998). Each examiner received a random selection of fifteen unknown fired bullets and Brundage found that all bullets could be correctly associated to the barrel from which they were discharged. As with case work, an inconclusive result was recorded by one of the participants, which was deemed by the author not to constitute an incorrect answer. Using the results from the study by Brundage, J. Hamby, (2009), expanding the study to produce two-hundred and forty tests, which were distributed worldwide, involving 201 participants and a total across both studies of 507 responses. Hamby found that there were no errors and except for a small number of bullets deemed to be unsuitable for microscopic examination, all remaining unknown bullets were correctly identified to the known/control bullets. In 2017, Owens completed a study examining the individuality of marks present on a bullet fired from one of five consecutively rifle barrels (Owens, 2017). Following multiple examinations, using comparative microscopy, this study confirmed that consecutively rifled barrels possess individual characteristics, that can be transferred to a fired bullet and subsequently used to identify the specific barre; through which the bullet was fired (Owens, 2017).

Further to these studies, Best and Gardner (2022), conducted an error-rate study into the identification of fired bullets from consecutively manufactured barrels. This study produced fifteen open-set comparisons, with five bullets in each kit damaged by common materials to replicate casework. The multiple participants compared the known to questioned bullets, with an overall error rate determined by the authors to be 1.36 +/- 0.41%. (Best and Gardner, 2022).

Another method has been to examine multiple cartridges discharged through a single firearm and comparing the microscopic marks on the ammunition components (Shem and Striupaitis, 1983 and Doelling, 2001). Recent studies have employed computer-based techniques to validate the accuracy of firearms examiners to differentiate between microscopic marks (Mattijssen, E.J. *et al,* 2019). The study by Mattijssen, *et al,* compared 400 test shots from 200 Glock pistols, which were compared by a computer-based method. Sixty of the resulting 79,800 comparisons were shown to 77 firearm examiners, with the results indicating the examiners appeared to be slightly less proficient at identifying same-source comparisons correctly, while they outperformed the computer-based method at identifying different-source comparisons. These studies provide a foundation for the ability of firearms examiners to distinguish microscopic striae and make determinations of fired ammunition components having a common source origin (i.e. discharged from the same firearm).

1.4.2 Integrated Ballistics Identification system (IBIS)

BulletTrax® is the bullet acquisition component of IBIS. It digitally captures the surface of a bullet in two- and three-dimensions, providing a topographic model of the striae and other marks around its circumference (Forensic Technology, 2014). The BulletTrax® component provides the macroscopic shape of bullets and microscopic surface details for later correlation (Forensic Technology, 2014). The other component of IBIS is the BrassTrax® system that captures two- and three-dimensional images of the cartridge head, along with individual images of the firing pin impression and breech face marks (Grom and Demuth, 2012).

These images created by the BulletTrax® and BrassTrax® systems of fired bullets and cartridge cases respectively are stored in the system's database and are converted to digital signatures that are sent to a server for correlation (Forensic Technology, 2014). The server provides a numerical score for each mark of interest using the system's algorithm, which scores the digital images to determine the best possible matches between the images (Grom and Demuth, 2012). The correlation score associated with a particular image indicates the strength of that match, such that a higher score will indicate a greater similarity in the physical attributes of the marks and therefore the stronger the potential likelihood of identification (Grom and Demuth, 2012).

An examiner is then required to view these potential matches using the MatchPoint+™ system, where they can rapidly visualise the potential matches, in place of conducting manual searches of potentially thousands of stored evidentiary fired bullets and cartridge cases. MatchPoint+™ is the comparative analysis component of IBIS by providing two- and three-dimensional images that enable the examiner to analyse the acquired bullet and compare it to previously examined bullets (Figure 1.3) (Forensic Technology, 2014).

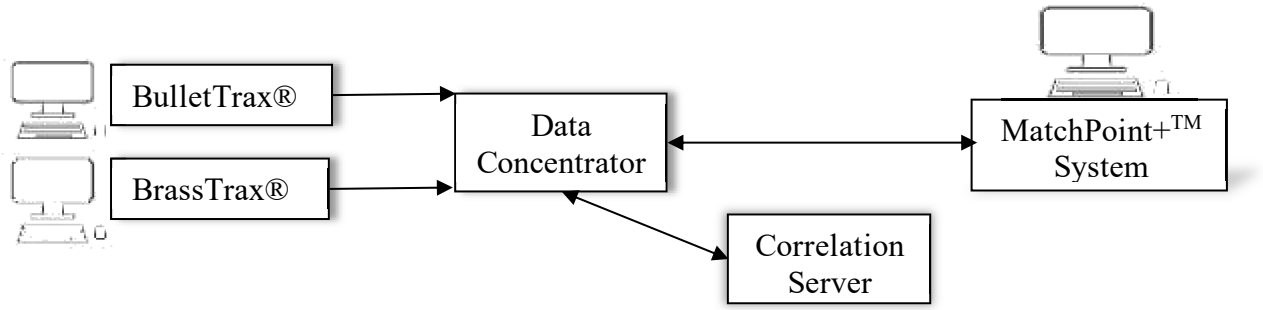


Figure 1.3: Schematic of the IBIS hardware components

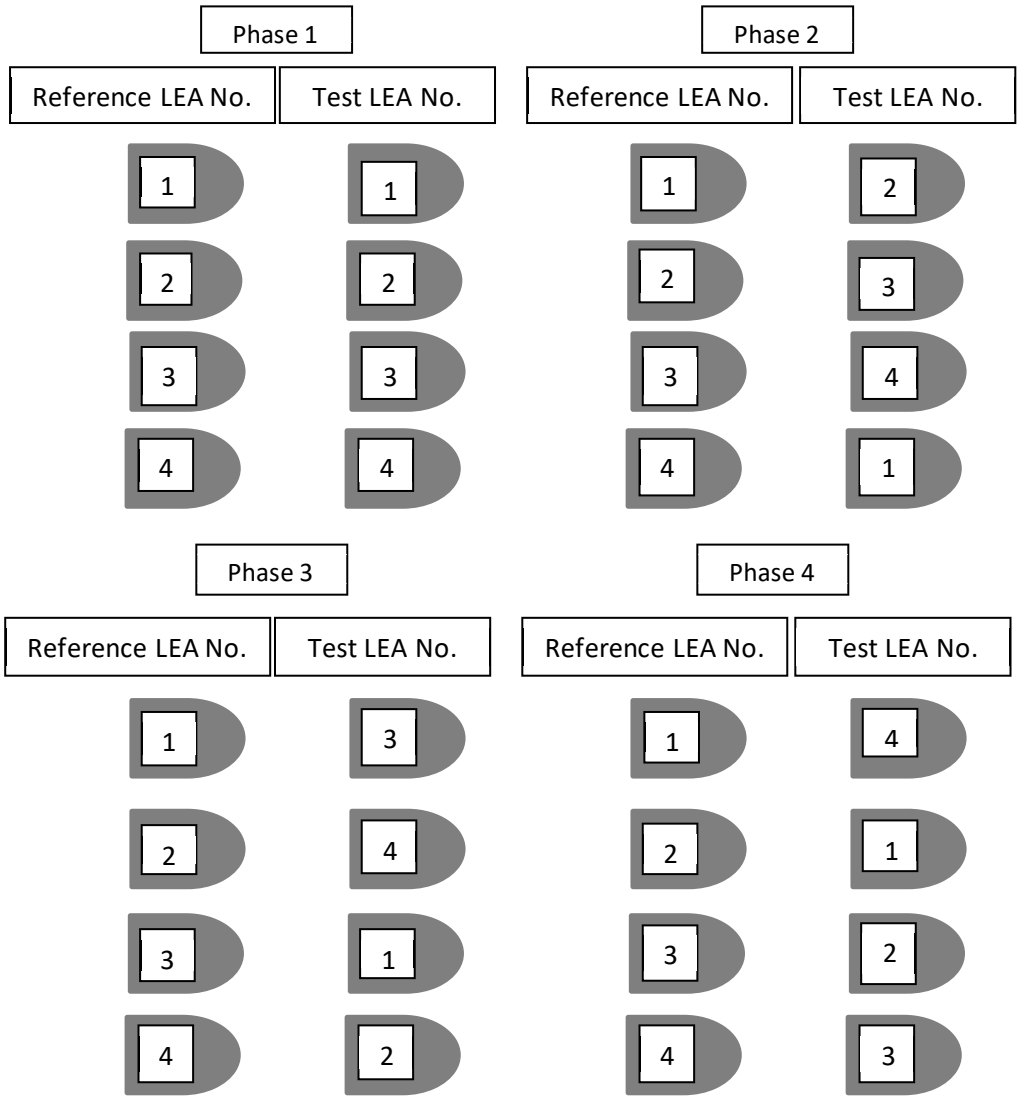
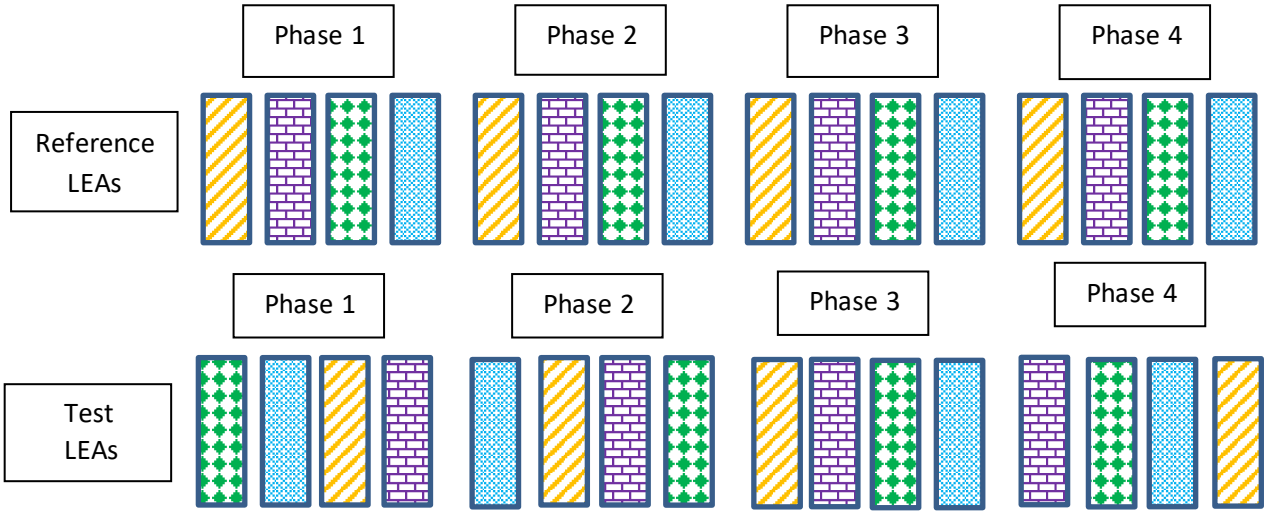


Figure 1.4: Comparisons between Reference LEA and Test LEA

For bullet exhibits, the correlation scores are based on the comparisons between reference (e.g., exhibit) and test fired bullets, where each LEA of the reference bullet is correlated to the LEAs on the test bullet (Figure 1.4) (Forensic Technology, 2014).

As an example, one fired bullet with four LEAs will generate 16 scoring LEAs per test bullet, and each group is called a Phase (Forensic Technology, 2014). The first phase of the correlation involves LEA1 of the reference bullet being compared to LEA1 of the test bullet, LEA2 to LEA2 and so on; Phase 2 involves LEA1 of the reference bullet being compared to LEA2 of the test bullet, LEA2 to LEA3 and on in order to compare all LEAs of the reference bullet to all the LEAs on the test bullet (Figure 1.4, Forensic Technology, 2014).

After the comparisons are completed, scores are calculated using the proprietary algorithm from the comparisons between the reference and test bullets as outlined in Figure 1.5. This can be demonstrated below, using coloured bars to represent the different striae patterns within the four LEAs on the bullets from Figure 1.4 and an arbitrary scoring system for illustrative purposes (Forensic Technology, 2014):



	Phase 1	Phase 2	Phase 3	Phase 4
Individual LEA Scores	1:1 = 130	1:2 = 105	1:3 = 536	1:4 = 115
	2:2 = 120	2:3 = 085	2:4 = 654	2:1 = 105
	3:3 = 105	3:4 = 105	3:1 = 682	3:2 = 110
	4:4 = 110	4:1 = 100	4:2 = 628	4:3 = 100
Total Score	**465**	**395**	**2500**	**430**

Figure 1.5: Illustration of bullet comparisons and table of Individual LEA and Total Scores

Phase 3 has the highest consistent scores across all comparisons, giving rise to the *Max Phase Score* and therefore the best indicator of a potential matching pair of bullets (Forensic Technology, 2014). MatchPoint+^{TM} will then display to the examiner which bullets the system has calculated to be the most likely matching pair. The examiner will view the stored images on MatchPoint+^{TM} to determine if a manual examination using a comparison microscope is required to confirm an identification.

The IBIS MatchPoint+^{TM} system ranks fired bullets based on their likelihood of a corresponding match with other bullets of the same calibre, Land Engraved Area (LEA) number, twist direction, width, and striae present. This system is objective and based upon a proprietary algorithm developed by the manufacturer, Forensic Technology Inc.

The MatchPoint+^{TM} version 3.1 system has two filters for assessing results, being a Unified Score, (with a threshold of 0.8) and the ability to filter the top twenty correlation results. The Unified Score uses a threshold of 0.8 applied to the correlation results and is a figure that has been determined by the manufacturers of MatchPoint+^{TM} to produce a better correlation performance than the top twenty filter (Pronpattanapairoj, 2023). The appearance of an exhibit within the correlation output does not indicate that a 'hit' has been made; however, it is highlighting the potential link between two items and the possibility of an identification to be made, based upon the acquired images (Nichols, 2019).

In version 3.1, the Unified Score, is calculated from a combination of individualised normalised matching scores for each Land Engraved Area (LEA), which are the normalisation scores based upon the entire correlation data set (Forensic Technology, 2020). The normalised score uses 'statistical methods in a standardised range' with the results plotted on a logarithmic scale (Pronpattanapairoj, 2023). This 'statistical method' is proprietary information; however, it is utilised by users of the system to assist in determining the most likely bullet (or cartridge case) matches. The Unified Score value represents the overall similarity of a correlation result relative to the other results in that set (Pronpattanapairoj, 2023).

The Top Twenty filter is a tool applied by MatchPoint+^{TM} to provide the highest chance of including exhibit fired bullets and cartridge cases in a correlation request, for further viewing by a qualified examiner. The top twenty filter can be applied after the MatchPoint+^{TM} system has sorted and ranked the images based on the phase scores (in the case of fired bullets) as described above, which is the 'Rank Sort' score (Pronpattanapairoj, 2023). A study by Nichols analysed the top twenty filter for fired cartridge cases and found that over a three-month period, 902 'leads' were identified (i.e., possible matches from the acquired images) on the US National Integrated

Ballistics Identification Network (NIBIN). NIBIN links local, state and federal agencies to a national ballistics imaging database of fired ammunition components, in a similar fashion to the Australian Ballistics Information Network (ABIN). From these 902 links, Nichols was able to filter these correlation results by exhibits on NIBIN that were ranked in the top ten and top twenty by the 'Rank Sort' scores. Nichols found that up to 87% and 95% of all possible leads would be detected in the top ten and top twenty results respectively (Nichols, 2019).

Any degradation of the microscopic striae on the bullet surface will influence the ability of the firearms examiner to identify these features and therefore form an opinion on the identification of fired bullets. As with comparison microscopy undertaken by a firearms examiner, any degradation will also influence the ability of the IBIS system to capture the surface of the bullet and the algorithm to assess the features and compare them to other images stored on the system's database. Therefore, any loss of surface features will likely lead to a fired bullet being given a lower score by the algorithm (meaning less chance of an identification) or not included at all in the list of potential matches. These false-negative results will mean the IBIS operator will not be aware of potential identifications, possibly hindering investigations into the incident.

1.5 Environmental Conditions and Bullets

Fired ammunition components are occasionally discovered and collected from crime scenes after exposure to the environment. This exposure can involve a number of local factors that can affect the degradation of the fired bullet and fired cartridge cases. Studies have been conducted on fired ammunition components that have been exposed to water and decomposing tissue and have found that these items corroded at much faster rates than fired ammunition exposed to the open-air environment or in loam forest soil over the same time periods (Larrison, R.M. 2006). Another study has involved examining the mechanism of atmospheric corrosion on fired bullets and cartridge cases in low-medium corrosion environments (Kerkhoff *et al.* 2014). This study found that brass and steel samples corroded relatively rapidly in the environment, whilst lead bullets were the least affected by corrosion. Earlier studies involving fired cartridge cases being exposed to a warm, dry desert environment for an extended period. The author reported that tarnishing and discolouration did occur on all of the cartridge case samples, however the tarnishing rates observed by the author did not vary significantly between different brands of cartridge cases (Bridgemon, 1986). A study conducted by Bryant *et al,* (2019), involved investigating the rates of corrosion of fired cartridge cases. Although not involving fired bullets, the authors found that the rate of corrosion was not a good indicator of the age of the fired cartridge cases, and that only seawater provided pronounced changes in the appearance of the cartridge cases. Therefore, using

environmental factors to determine the age of fired ammunition components remains difficult and subject to many external factors.

1.6 Decomposition and Bullets

Bullets are often retained within the body and exposed to decomposition processes, especially if the body is not recovered within a relatively short timeframe. This is likely to impact the bullet and complicate analysis due to the processes occurring during decomposition. Shortly after death, the body begins to decompose primarily via two processes: autolysis and putrefaction. Autolysis is the destruction of the cells by enzymatic digestion, resulting in their eventual rupture and the release of fluids from the body (Vass, et al, 2002). Autolysis commences within minutes of death and is caused by the lack of oxygen inhibiting aerobic metabolism (Carter et al, 2007). Autolysis may not be outwardly apparent for days but is initially observed by the development of blisters and skin sloughing after which, putrefaction begins (Vass, et al 2002). Putrefaction differs from autolysis, as this involves microorganisms destroying soft tissue and is initially indicated by a green discolouration due to the formation of sulfhemoglobin in the blood (Vass, et al, 2002). The green-purple discolouration in the lower abdomen occurs by the growth of colonic bacteria (Iqbal, et al, 2018). Decomposition can be related to six stages (Carter *et al*, 2007) although five stages (fresh, bloat, active decay, advanced decay, and skeletonisation/dry remains) have also been suggested (Iqbal, *et al,* 2018).

Autolysis and putrefaction lead to a host of chemicals (Iqbal et al, 2018; Vass, et al, 2002) being present in the cadaver resulting from the cellular and microbial breakdown of the tissue, which may be responsible for damaging embedded bullets. The lack of oxygen precipitates autolysis, where carbon dioxide in the blood increases, lowering the pH (Vass, 2002). Putrefaction causes the formation of gases that include hydrogen sulphide, methane, ammonia, and sulphur dioxide (Vass, et al, 2002). The formation of these gases is also associated with butyric and propionic acids (Vass, 2002). This chemical environment may result in any embedded bullets being damaged and therefore unsuitable for comparison work or may result in inconclusive results between the unknown bullets from the deceased and the known bullets from an exhibit firearm. Adipocere may also form in the advanced decomposition stage, especially in wet conditions (Galloway, 1997) Adipocere is a waxy organic substance formed by the anaerobic bacterial hydrolysis of fat in tissue and can play a role in decomposition rates (Carter and Tibbet 2008).

A notable case in Australia, where decomposition was an issue in identifying exhibit fired bullets to a single firearm was during the ‘Backpacker Murders’ investigation from New South Wales in the early 1990s (Dutton, 1993). One of the first two victims recovered was shot ten times; seven

fired .22 Long Rifle calibre lead bullets were recovered from the skull of the deceased and three fired .22 Long Rifle calibre lead bullets recovered from the soil beneath the victim (Dutton, G. 1997). These bullets had been within or adjacent to the victim for approximately 5-months, and each of the ten bullets was able to be identified to each other, indicating the same firearm was used in the homicide (Dutton, G. 1997). It was reported by Dutton, that this body had been in the Belanglo State Forest during the Australian winter period and had been in a shallow grave, under a large rock overhang. Conversely, one of the last victims recovered, had been shot six times and the recovered bullets examined were unsuitable for any comparison work, due to the corrosion and scale on the fired .22 Long Rifle calibre lead bullets. These bullets had been contained within the decomposing victim for approximately 22 months; this time was taken as being from the last confirmed sighting (26th December 1991) to the discovery day (4th November 1993) (Dutton 1997). This implies that the deceased was exposed to the elements for two Australian summer periods, when temperatures are relatively warm in this region, southwest of Sydney; the mean maximum temperatures for January are approximately 26.3^{O}C and 11.9^{O}C in July.

Other affected investigations include a homicide in 2007, where the victim was shot, covered in lime and buried in a bush grave (Pieterse, 2007). The victim was discovered two months after the homicide and the decomposition process rendered the bullets located within the victim inconclusive to the test fired bullets from the suspect firearm (Pieterse, 2007).

1.6.1 Human versus Pig Analogues

Pigs have become model human analogues in forensic entomology and taphonomy (Matuszewki. *et al* 2019). Pigs have been employed in forensic science research due to their similarities in internal anatomy, gut biota (Knobel *et al.,* 2019) and fat-to-muscle ratio, tissue density, distribution of body hair and omnivorous diet (Conner, *et* al., 2018). Pigs are used in these research settings as the cadavers may be replicated in larger numbers and without the wait-times and ethical considerations of using human donors (Matuszewki, et al 2019). Pigs also offer better control of replicate samples, and several concurrent research treatments can be applied to a number of pig carcasses, which allows for inferences to be made about human decomposition (Matuszewki. *et al* 2019).

There have been some criticisms of using data from pig decomposition studies to extrapolate to human decomposition processes (Connor, *et al,* 2018) and human donors and pig carcasses clearly exhibit variable sizes, fat and muscle composition and hair distribution and may decompose differently to one another. However, this can also be an issue with human donors, as the majority of donors are elderly and have died from natural causes as compared to deceased at forensic-related

scenes, who have often died from unnatural causes (Matuszewki, S. *et al* 2019). Visual findings of pig decomposition have not been found to be a reliable analogue for human decomposition patterns in the Sydney region (Knobel, *et* al, 2019), yet pigs have been used as a compromise between the availability, ethics, anatomical similarities, and microbial/insect activity. This study seeks to compare human donors and pig carcasses by exposing a number of fired bullets with the same metallic composition (i.e., copper and lead) using a number of pig and human replicates in similar environmental conditions.

1.6.2 Trauma and Decomposition

One aspect of this research is the multiple trauma sites that will be created in the pig carcasses and human donor to place the fired bullets into the target regions, being the lungs, abdominal cavity and leg muscles, which were selected for this project due to the different tissue composition of these areas and the internal bacterial population in each tissue type, specifically the abdomen. One study has reported that order of magnitude estimates for the concentration of bacteria (by organ volume) that reside in the different human organs can range from 10^3 (stomach) to 10^{11} in the colon (large intestine), for a 'standard 'Reference Man' being defined as between 20 – 30 years old, 170cm in height and weighing 70kg (Sender *et al,* 2016).

Whilst there does not appear to be data from Australia, several studies have been conducted into the location of gunshot wounds in both fatal cases and presentations to hospital emergency departments, which assisted in deciding on target regions. One study of fatal wound locations found that in rifle and handgun shooting incidents, the head was targeted in 21% of all cases, the chest and abdomen were struck in 17% and 6% respectively in rifle cases and 12% and 2.8% respectively in handgun cases; the extremities were reported in 3% for rifles and 1.2% for handguns (Molina and DiMao, 2008). A second study found firearm injury locations presented to the Hacettepe University Emergency Department in Ankara, Turkey, between the 1st of January 1999 and the 31st of December 2013 identified that the head was targeted in 31% cases; the chest, abdomen and lower extremities were targeted in 25%, 11% and 48% of presentations respectively, where some incidents involved multiple injury sites (Karaca, et al, 2015). A third study from the United States of three trauma centres in the state of Kansas identified that the head was targeted in 2.7 – 10% of presentations, the chest targeted between 19.4 – 29.7% the abdomen and extremities were struck in 8.8 – 16.2% and 21.5 – 32.4% of cases respectively (Benton, et al. 2021).

Research has been conducted into the effect of penetrative trauma, blood loss and rates of decomposition (Cross and Simmons, 2010 and Cockle and Bell, 2019), but whilst temperature and

humidity are the main contributing factors in decomposition processes, trauma may impact upon decomposition by increasing access to the cadaver for insects through open wounds (Cross and Simmons, 2010). Research conducted at the Anthropology Research Facility (ARF) in eastern Tennessee, United States (Mann, *et al* 1990) reported that on a subjective decay rate scale (1 – 5), penetrative/crushing trauma scored 4 out of 5 in terms of the effect on the decay rates of the human body. In the same study, temperature and insect activity rated 5 in terms of decay rates.

Mann *et al.* noted that two bodies placed on the ground in an open site at ARF at the same time, one with a penetrating gunshot wound, decayed at a faster rate than the other body without such trauma. The authors also reported that the flies were immediately attracted to the penetrative wound on the body where early egg laying took place and was the first area to display extensive maggot activity, involving feeding and tissue destruction (Mann, *et al* 1990).

Research by Cross and Simmons used several pigs that had been shot with a handgun to produce multiple penetrative wounds and study the effect on the decomposition rates. The shot pigs were left in an open field in the United Kingdom during the warmer summer period, and decomposition recorded using a Total Body Score (TBS) as presented in previous research, body weight and temperatures, ambient temperatures, and soil pH (Cross and Simmons 2010). The study suggested that the rate of soft tissue destruction in the pigs shot with the handgun did not differ significantly from the non-trauma group of pigs and whilst the penetrative wounds did provide access to soft tissue, egg-laying by insect species noted in the study did not occur preferentially at the trauma sites, when compared to natural orifices in the head (Cross and Simmons, 2010). This study did not look at the role of trauma specifically, however effect of temperature was addressed by conducting the studies at different times of the year to address temperature and humidity variables.

1.6.3 The Effects of Decomposition on Fired Bullets

There have been relatively few articles investigating the effect of decomposition processes on fired bullet striae and the work completed thus far has been confined to the Northern Hemisphere (Love, 1980, Smith *et al*, 1993, Chow *et al,* 2003 and Rao *et al*, 2015). The first reported study from 1980 (Love, 1980), presented results from a number of bullet types both exposed to human blood and stored in two different environments: indoor controlled condition or an outdoor environment. The bullets stored in the indoor controlled conditions were readily identifiable and showed little sign of corrosion; the bullets in the outdoor environment were still identifiable but with pronounced loss of identifiable characteristics and proved difficult to adequately clean (Love, 1980). This study used blood only and did not consider the complex chemical and microbial environment generated during decomposition processes. This limited the results as it does not reflect a real-life scenario.

In addition, the study did not offer any detail regarding timelines of when damage to the bullets were observed.

In 1993, Smith *et al*. used different bullet types placed in specific tissues to investigate the effects of decomposition on bullet striations using a human donor. The bullets were examined, and a corrosion scale developed and used to report the changes on the bullets. It was found that copper and nickel bullets were the most reactive with severe dissolution and scaling, with lead bullets displaying a 'fluffy' oxide residue being formed, whilst the aluminium and nylon bullets displayed the least damage (Smith et al., 1993). The authors also reported that the greatest overall effects on the bullets were found in bullets exposed to muscle and fat tissue. The differing pH and microbial activity in these organs were suspected to be the cause of the different damage levels of the bullets. In terms of pH levels, mammalian blood is maintained at a pH of 7.4 (Moi and Marunaka, 2014) and decreases to pH 6 and 5.7 in the small intestine and caecum respectively (Fallingborg, 1999). Similarly, to Love (1980), no specific timeframes relating the exposure time of the bullet to the decomposition environment and the corrosion to the bullet's surface was mentioned. Instead, bullets were all collected after 66 days, and damage could therefore have occurred at any time prior.

A number of different bullet types were inserted into pig carcasses in a study by Chow, *et al,* (2003). The pigs were allowed to decompose, and the bullets removed at pre-determined intervals. The recovered bullets were assessed for their deterioration similar to Smith *et al*, 1993. In general, the authors found that aluminium was the least affected by the putrefaction process, with brass bullets then copper-jacket bullets being the most affected, which is consistent with the findings from Smith *et al*. (1993). The study showed promising results for the use of bullet corrosion resulting from decomposition processes as an additional tool in estimating time of death.

Although the study showed promising results, the bullets were not inserted into specific organs where decomposition may alter the surface corrosion due to the different tissue types, chemical environments, and microbial populations. For example, pig colon has been shown to contain anaerobic *streptococci, lactobacilli eubacteria* and *clostridia*, although this population is susceptible to changes in the diet (Leser, *et al*, 2000). The microbial gut population can change at different ages and growth cycle of pigs, with some bacteria described as 'core' members of the gut, being present throughout the life of the pig (Yuheng, *et al,* 2022). From this, it was difficult to determine which regions of the body were responsible for the corrosion effects reported. This non-specific placing also caused bullets to be lost within the carcass and therefore never retrieved.

The effect of decomposition on bullet striae has also been studied in human cadavers in different environmental conditions (Rao, *et al*, 2015). In this study, half of the bullets were exposed to muscle tissue in a cadaver placed in an outdoor tropical environment and the other half exposed to muscle tissue in a cadaver in a mortuary cool room (Rao, et al, 2015). A bullet was retrieved every 48-hours from the cadaver in the outdoor environment for a period of twelve days, whilst the bullets from the cadaver in the cool room were removed at day twelve only. The authors reported that naked eye analysis showed that by day four the class characteristics of the bullets in the outdoor cadaver were obscured. The class characteristics were obscured by day eight. These results must be assessed carefully as the results reported were based on the percentage of bullet striae obscured at each recovery day. This reporting was not done in accordance with accepted procedures within the forensic firearms field of reporting results based upon the Association of Toolmark and Firearm Examiners (AFTE) Range of Conclusions (Appendix 3). This means that the results from this study cannot be readily compared to the others. Despite this limitation, the study did observe damage rapidly and suggest that obstruction of characteristics do occur within a short timeframe in decomposing victims, highlighting the need for further investigation.

1.7 Research Aims and Objectives

The limited research into the effect of decomposition processes on fired bullet striae has been confined to the Northern Hemisphere. There have been no published studies completed of this type in an Australian context.

The influence of the type of tissue putrefaction on the fired bullets may be determined by the microscopic identification of bullet striae by trained examiners and automated systems. This is important as the area from where the bullet was recovered may produce different effects on the bullet's surface. Without knowledge of where the bullet was recovered from, the subsequent corrosion may provide investigators with an incorrect time-of-death estimate, based on the microscopic examinations and general surface observations. Therefore, bullets exposed to different tissue need to be prioritised and removed at specific time intervals to determine if there is an approximate point at which the striae are no longer identifiable. This approximate point where the striae are no longer identifiable, may also inform investigators as to an approximate time-of-death.

The aim of this research was to investigate the impact of decomposition on the degradation of fired bullet striations via corrosion mechanisms, which may be used to determine the degraded bullet's potential for time-of-death estimation. This research aims to identify when fired bullets may no longer be identifiable, after targeting specific tissue types and regions within decomposing human

and pig analogues through the development of a corrosion scale, microscopic examinations utilising qualified firearms examiners and computer-based correlations of the sample bullets.

Chapter 2: Materials and Methods

Chapter 2: Materials and Methods

2.1 Introduction

The project has been divided into pilot, field, and examination phases. The pilot was initiated to determine the best method of exposing the bullets to biological fluid and determine the methods used to insert and retrieve bullets in the subsequent field studies.

The field phase commenced with the firing and collection of the subject bullets using firearms held by a local law enforcement facility. The bullets were prepared for insertion into the pig analogues and human donors, which were left to decompose at the Australian Facility for Taphonomic Experimental Research (AFTER), a research facility owned and operated by the University of Technology Sydney (UTS). The fired bullets were sequentially removed from the pig or human donor and returned to the forensic facility where the examination phase commenced. This phase involved qualified firearms examiners undertaking independent microscopic analysis of the retrieved fired bullets, with their conclusions of common origin collected to determine if any affect from the decomposition process was observed on the fired bullet striae.

2.2 Bullet selection

The ammunition that was selected for both pilot and field studies was from the police facility's ammunition store. The 9mm Parabellum calibre Norinco model NP22 self-loading pistol and a .38 Special calibre Smith & Wesson model 14 six-chamber revolver was used to discharge the selected ammunition were sourced from the police facility's Firearms Reference Library, which is a secured area containing firearms that are used in casework by the examiners employed within that firearms section. Prior to selecting the bullet samples for the pilot and field phases, data was sought to determine the most prevalent bullet types encountered in casework. Data indicated that .22 Long Rifle calibre fired bullets had the highest number of matches on the New South Wales Police Integrated Ballistics Identification System (IBIS), followed by 9mm Parabellum ammunition with the second highest calibre matches on IBIS, and then .38 calibre bullets (this calibre designation includes .357 Magnum, .38 Special and .38 Super calibre) which was the third highest calibre with recorded matches. 9mm Parabellum and .38 Special calibres were selected as they are commonly encountered in casework and account for approximately 29.9% and 6.1% respectively of the bullets captured on IBIS (ACIC, 2021). However, .22 Long Rifle bullets were not selected, despite their prevalence, primarily due to their relatively small diameter and potential for loss within the decomposing bodies. 9mm Parabellum calibre 124grain FMJ copper bullets and .38 Special calibre 158grain lead bullets were used for the study, as they are larger bullets and relatively easier to

work with and examine. .45 Colt calibre bullets were later selected to replace the .38 calibre bullets, due to the better marks made by the .45 calibre rifles on these bullets produced by the .45 Colt calibre Winchester model 1892 used. Both .38 and .45 calibre bullets are comprised of a similar lead alloy composition produced by the Winchester® company. Due to restricted timeframes, the quality of the .38 fired bullets were not assessed, however after the initial results, it was decided to fire and compare these bullets to the .45 Colt calibre bullets.

2.3 Bullet preparation – Pilot study

The bullets for the pilot study were fired into a bullet recovery water tank using a firearm held by the New South Wales Police. The ammunition was obtained from the police ammunition store and using the selected pistols, the ammunition was discharged into a bullet recovery water tank manufactured by W.E Platt Industries, Sydney, New South Wales. To obtain fired bullet samples, a 9mm Parabellum calibre self-loading pistol was used.

After collection from the water recovery tank, the bullets were dried, each of the bullets had a small hole drilled into the base and tapped with a metallic eyelet (Everhang®) to which a length of picture framing wire (Everhang®) was attached. This ensured the bullets were able to be recovered during the field studies. Differing attachment methods were considered initially, which included directly gluing wire or small wooden dowels to the base of the bullet. Given the timeframes and resources available, a 'physical' method of attachment was determined to be the most suitable. Once it was decided to use a metal eyelet and picture framing, differing types of each was further tested.

Six fired 9mm copper jacketed bullets each had a small hole drilled into the base and tapped with either a brass or zinc-coated a metallic eyelet (Everhang®) to which a length of either metal (zinc), or polymer coated picture framing wire (Everhang®) was attached. 9mm copper jacketed bullets (one with a zinc eyelet and zinc metal wire and the other with brass eyelet and polymer-coated wire) were placed in were each placed in one Schott bottle sourced from the New South Wales Police laboratories at Pemulwuy, Syndey. The bottles were labelled either Bottle 1 for the bullets with the zinc eyelet and zinc wire or Bottle 2 for the bullets with the brass eyelet and polymer-coated wire. Each bottle contained one litre of cattle blood also sourced from the New South Wales Police laboratories at Pemulwuy, Syndey. No animal ethics were required for the use of animal blood at this stage (Table 2.1). The fired bullets were suspended in the blood, ensuring that the bullets did not touch the bottle sides or other bullets to ensure complete exposure. The sample preparation day was designated as Day 0. Bullets were removed on days 7, 14 and 21 from the two differing conditions. A control bullet (not exposed to blood) was also monitored. After each

pair of bullets were removed from the blood, the bullets were then cleaned using a 5% bleach solution (CleeraWinc®, Sydney) and placed in an ultrasonic cleaner for approximately five minutes, before being rinsed in cold tap water, and dried by an air hose and stored.

Table 2.1: Pilot study eyelet/wire combinations

Bullet type	Eyelet type	Wire type	Removal Day
9mm copper (Bottle 1)	Zinc	Zinc	Bullet 1: Day 7 Bullet 2: Day 14 Bullet 3: Day 21
9mm copper -(Bottle 2)	Brass	Polymer-coated metal	Bullet 4: Day 7 Bullet 5: Day 14 Bullet 6: Day 21

2.4 Bullet preparation – Field study

The bullets for the field study were fired into a bullet recovery water tank using firearms held by the New South Wales Police. The ammunition was obtained from the police ammunition store and using the selected pistols, the ammunition was discharged into a bullet recovery water tank manufactured by W.E Platt Industries, Sydney, New South Wales. To obtain fired bullet samples, a 9mm Parabellum calibre self-loading pistol, a .38 Special calibre six-chamber revolver and a .45 Colt calibre rifle was used.

When collected from the water recovery tank and dried, the bullets each had a small hole drilled into the base and tapped with a metallic eyelet (Everhang®) to which, a length of picture framing wire (Everhang®) was attached. The other end of the wire had a coloured plastic keyring (J. Burrows®) secured for identification purposes.

2.4.1 Field Site

This work was conducted at the Australian Facility for Taphonomic Experimental Research (AFTER) and an animal decomposition research facility, which is operated by the University of Technology Sydney (UTS). These two facilities are located approximately 300 metres apart; both areas have an identical environment in open wooded regions with low scrub (Blau, S. *et al.* 2018 and Deo, A *et al,* 2020). The general area is typically described as Cumberland Dry Sclerophyll

Forest with sandy clay loam or gravelly sandy clay and encompasses a high security facility and an adjacent test area (Knobel *et al,* 2018).

2.4.2 Human Donors and Pig Carcasses

Trials were undertaken in cool and warm conditions to investigate the influence of the environment in addition to the bullet damage (Figure 2.1). Three recently euthanised domestic pigs (*Sus scrofa domesticus*) weighing approximately 50 kg sourced from a licensed facility were used for the human analogue studies. The pigs were placed onto their back and the pre-fired bullets inserted by creating incisions to target the lungs, abdomen, and leg muscle (Figure 2.2). Seven (7) bullets of each type (lead and copper) were prepared as outlined in section 2.2.2 and inserted into the specific tissue locations (Figure 2.2). A wire mesh cage was placed over the pig carcasses to allow insect activity and exposure to the environment but deter predation by larger animals No animal ethics was required as the pig carcasses used in this study did not include living or foetal subjects, conforming to the Australian Code of Practice for the Care and Use of Animals for Scientific Purposes (2013, NHMRC, 2023). The pig carcasses were purchased post-mortem from a licensed abattoir. All pigs were killed by captive-head bolt following the standard guidelines for Australian abattoir procedures.

Two unclothed male human donors, (one 70-year-old male who had died from cancer and one 56-year-old male who had died from cardiovascular disease) were placed in the supine position within the AFTER facility. The human cadavers used in this study were acquired through the UTS Body Donation Program overseen by the Surgical and Anatomical Science Facility (SASF) at UTS. Consent was provided by all donors to use their remains for the purposes of research at AFTER, in accordance with the New South Wales Anatomy Act (1977). The research project was approved under the UTS Human Research Ethics Committee Program Approval (UTS HREC REF NO. ETH18-2999).

Similarly, to the pig carcass, the bullets were inserted into specific areas of the donor (Figure 2.2), with a wire cage placed over each donor to deter predation from larger scavengers, whilst allowing insect activity and exposure to the environment. Images were taken of the donors and pigs during each sampling day to visually monitor the decomposition over the course of the study and the rates of decomposition were based on those described by Galloway, 1997. For this thesis, the ‘bloat’ stage is incorporated under ‘early decomposition’ and not a separate stage, as described by Iqbal, *et al,* 2018.

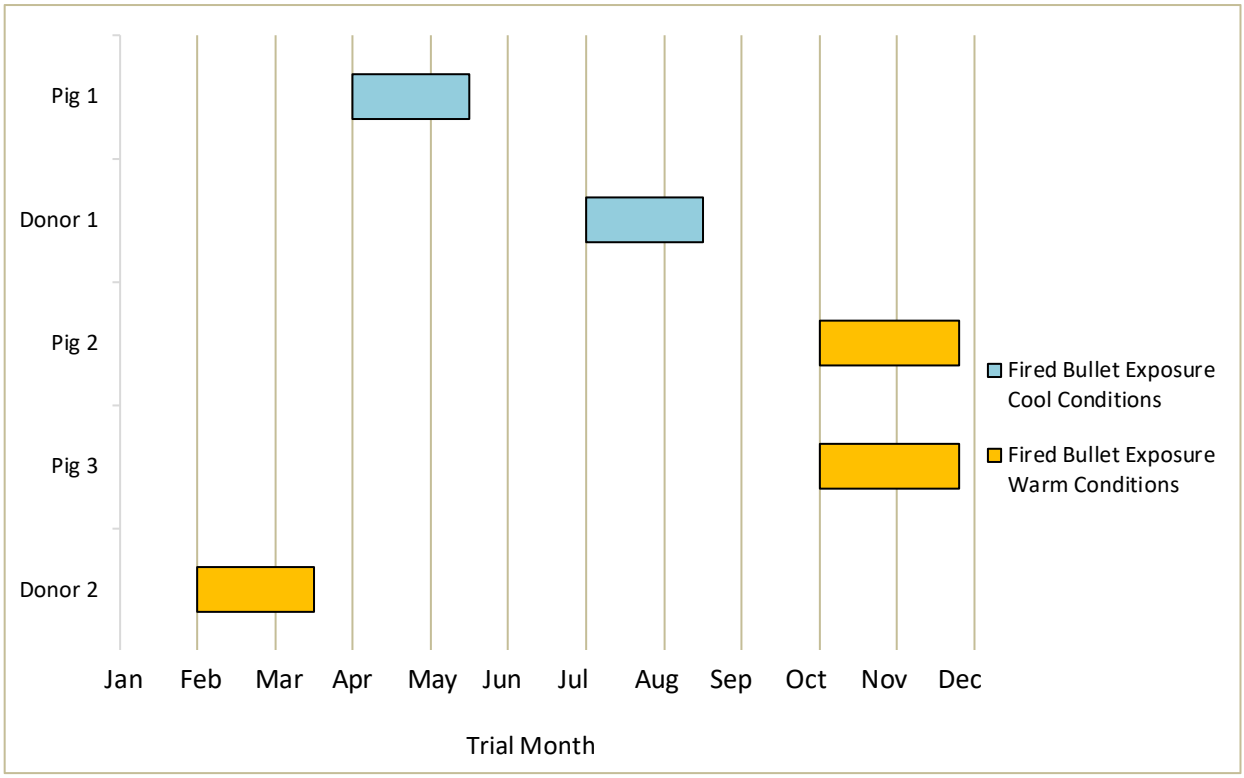


Figure 2.1: Fired bullet exposure periods for all Pig and Human trials.

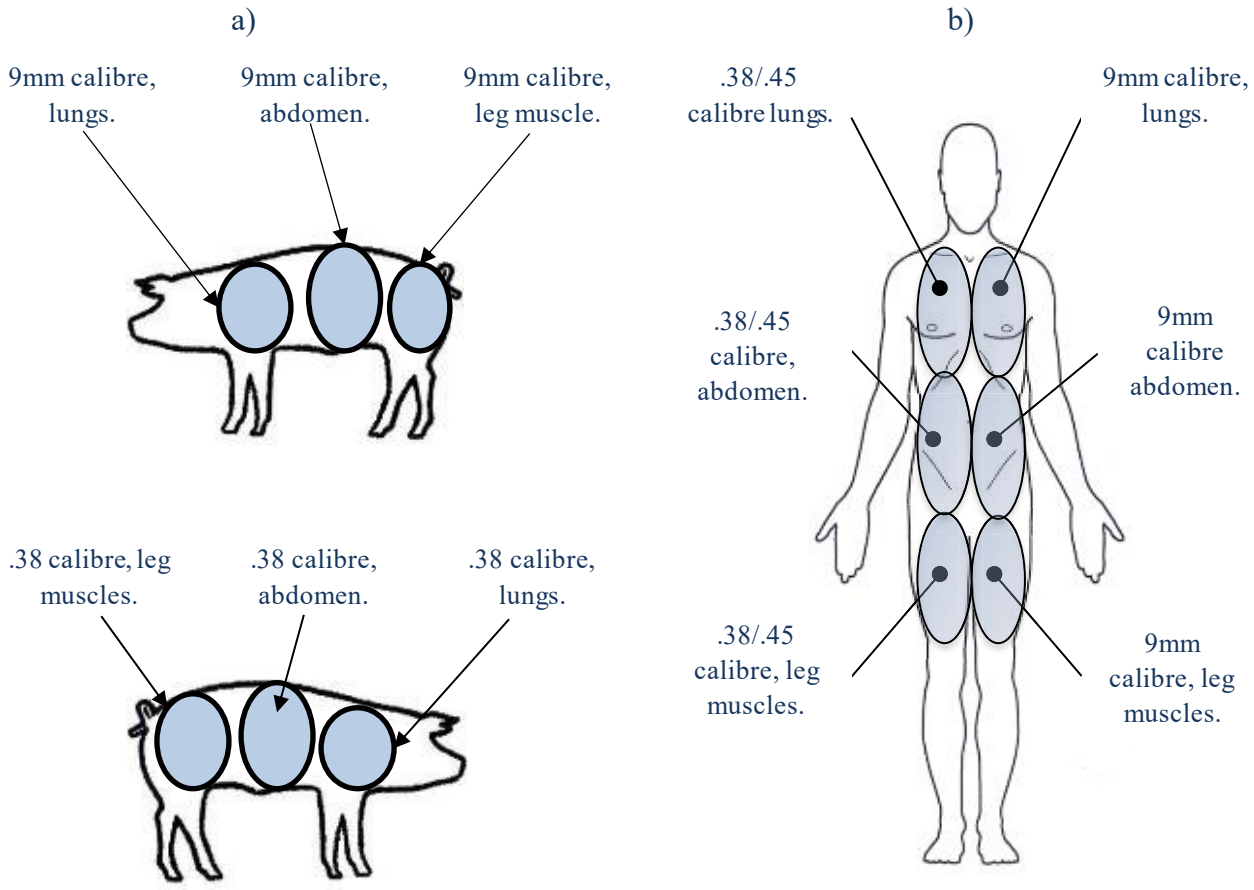


Figure 2.2: Location of (a) insertion sites for pig carcases and (b) insertion sites for human donors

Additional bullets of each calibre were kept as controls devoid of contact with decomposing remains. Control bullets were maintained in laboratory conditions, which was to replicate operational casework. In this project, it was decided to blend operational forensic procedures with the academic requirements of the project; therefore, the fired bullets exposed to the decomposition processes were from a 'victim' located in a bushland setting (i.e., pig and human donor) and then compared to the test fired bullets (controls) retained in the lab. It was also determined not to be practical to subject control test bullets solely to environmental conditions for comparison to the test bullets maintained in the lab and/or those recovered from the carcasses/donors. This comparison between bullets exposed to the environment and those exposed to the decomposition process would not serve any practical value to forensic firearms examiners undertaking casework. The remainder of the project was designed to assess the effect of the decomposition environment on fired bullet striae. The project already included several variables, including bullet type, (copper and lead bullets), environmental (temperature) and species differences (human vs, pig). By including bullets exposed solely to the environment, this would introduce other variables, that a bullet lodged within a body would not be exposed to, such as rain.

2.4.3 Bullet collection and processing

The cool weather trials involved one pig (Pig 1) and one human (Donor 1) whereas the warm trial consisted of two pigs (Pig 2 and 3) and one human (Donor 2) (Table X). Samples were collected every 3 days post-placement until day 21.

Table 2.2: Pilot study specimens and sampling days

Trial	Specimen	Sampling days
Cool	Pig 1	3, 6, 9, 12, 15, 18, 21
	Donor 1	
Warm	Pig 2	
	Pig 3	
	Donor 2	

The bullets were retrieved from the pig and humans and cleaned in the field using a Bleach solution (CleeraWinc®, Sydney) and rinsed with water to ensure they did not pose any biological hazard and that no further degrading of the striae occurred. The bullets were then placed into specimen tubes and returned to the Ballistics Investigation Section (BIS). At BIS, the bullets were again cleaned using a 5% bleach solution (CleeraWinc®, Sydney) and placed in an ultrasonic cleaner (EMAG®) for approximately five min, before being rinsed in cold tap water, dried, and

labelled according to a naming system reflecting donor, region and day post-mortem (using alphabetic character to ensure no bias during analysis) (Appendix 2, Table A2.1).

2.5 Examination Phase

The recovered and cleaned bullets were examined using Leica FS-C (Leica Microsystems, 2020) and Projectina Vision-X comparison microscopes. The twelve fired 9mm copper jacketed bullets from the pilot study were examined to determine which eyelet/framing combination would be suitable for future field studies. Microscopic analysis and photography of the bullets exposed to the cattle blood was conducted to determine if the striae were affected by the blood over a three-week period.

The analysis of the bullets from the field phase was carried out by the researcher and five volunteer participants. The participants were all microscopic trained Forensic Firearms Examiners and Australasian Forensic Science Assessment Body (AFSAB) experts from the Australian Federal Police (AFP), Tasmania Police Force (TASPOL), and New South Wales Police Force (NSWPF). The participants that were employed at the AFP and NSWPF were provided with instructions on the requirements of the microscopic examinations and reporting procedures in person. Participants from TASPOL were mailed the fired bullets with instructions. Each examiner involved was provided with all replicate sets of the recovered fired 9mm and .38 Special (SPL) bullet samples from the pig and human specimens, to examine microscopically. Each set consisted of three fired 9mm Parabellum calibre copper (material) and three fired .38 Special calibre lead bullets, from the respective tissue locations (lung, abdomen, and leg muscle) per each sampling day and control 9mm and .38 SPL fired bullets. The examiners did not know the location from where the bullets were collected or the time of bullet removal. Each examiner was required to examine the exposed and control bullets and report on any common source findings.

The trained participants reported their findings using the Association of Firearms and Toolmark Examiners (AFTE) Range of Conclusions and the Theory of Identification (Appendix 3). This is the accepted method employed in the Firearms Examination field for reporting conclusions of microscopic analysis (AFTE 2020).

The examination phase utilising the Integrated Ballistics Identification System (IBIS) was undertaken by the author at the Australian Federal Police forensic facility in Majura, Australian Capital Territory. This involved acquiring digital images of the control and exposed bullets using the BrassTrax™ system. The initial step is to place the bullet on a stand that rotates about the horizontal axis, whereby the embedded camera takes multiple images of the bullet's surface. These

images are then stored on a database and correlated against all other stored images using the MatchPoint+^{TM} system and proprietary software. This software produced a number of scores for the author to analyse, which was used to indicate the potential link between the control and exposed bullets.

2.6 Analysis

As decomposition is being studied to determine the effects on bullet striae, it was important to develop scoring systems to convey the data and determine what effects, if any, existed. Three visual scoring systems were employed for this research. The first scoring method was based on the reported AFTE Range of Conclusions, the second and third involved determining a Bullet Corrosion and Bullet Colour scales, respectively. The Corrosion and Colour scales were developed specifically for this project. A fourth (non-visual) Unified Score system using the Integrated Ballistics Identification System (IBIS) MatchPoint+^{TM} system was also employed using a score threshold of 0.8. Analysis using the data from the Integrated Ballistics Identification System (IBIS) was completed based on the two filters used by the MatchPoint+^{TM} version 3.1 system, being the unified score and top twenty correlation results. The analysis involved ranking each bullet's unified (with a threshold value of 0.8) and top twenty score. The scores do not indicate a hit but does highlight the potential 'link' between the control bullet and the bullets exposed to the decomposition processes and is based upon images acquired on to IBIS using the BulletTrax acquisition system. The unified score represents the overall relationship of a correlation result relative to the other results, therefore the greater the degradation of the bullet's surface, the greater the influence on the unified and top twenty correlation results. Any loss of surface features will likely lead to a fired bullet being given a lower score by the algorithm (meaning less chance of an identification) or not included at all in the list of potential matches.

2.6.1 Scoring based on the AFTE Range of Conclusions

The conclusions provided by the participants were assigned the scoring system:

- Positive identification (P) = 2 points,
- Inconclusive Result (I) = 1 point, and
- Unsuitable for comparison (U) = 0 points.

An overall score was obtained by applying the point scoring system to each participant's result by recovery area, taking the median of these points. The answers from the participants were recorded and graphed, with the participants only recording positive, inconclusive or unsuitable results and the results were separated by the subject body (pig or human), target tissue and ammunition type.

A review of the results from the participants was undertaken to determine if any false negative or false positive results were recorded. In the event of a false negative or false positive result being recorded, the overall results would have been had one of the following scores included (note: no false negative or false positive results were recorded):

- False Negative Result (FN) = -1 point, or
- False Positive Result (FP) = -2.

2.6.2 Corrosion and Colour scales

Two scoring systems were developed for the field study, a bullet corrosion scale (Tables 2.3 and 2.4) and a bullet colour scale (Tables 2.5 and 2.6). The bullets were graded on a scale of one (1) to five (5), with one representing the most damage or colour changes observed, whilst five represents the least damage from corrosion or colour changed observed. These scales were developed with forensic examiners working at crime scenes and forensic laboratories in mind, where the corrosion and colour scales may be used to inform investigators of possible post-mortem intervals, particularly when microscopic examinations were not possible due to the damage to the bullet's surface.

Table 2.3: Copper Bullet Corrosion Scale

Grade	Detail Visualised – Copper Bullets	Representative Images
5	• Evidence of Class Characteristics. • Individual Characteristics present. • <25% black scale formed that does not hinder examination, with limited/no discolouration of copper surface. Majority has untarnished copper surfaces.	
4	• Evidence of all Class Characteristics. • Agreement of Individual Characteristics present. • 25-50% scaling, corrosion and discolouration of copper surface that does not hinder identification **OR** • Any amount of scaling, corrosion or discolouration that does not hinder identification.	
3	• Evidence of Class Characteristics • Some agreement of Individual Characteristics, however insufficient to form identification. • 50-75% scaling or corrosion products present with discolouration of copper surface, hindering identification. • Some regions of untarnished copper jacket	
2	• Evidence of discernible Class Characteristics. • Little evidence of Individual Characteristics. • 75-100% coverage of corrosion, scale formed with discolouration of surface.	
1	• Some evidence of Class Characteristics. • No evidence of Individual Characteristics (no striae apparent). • ~100% heavy corrosion, scale formed with discolouration of copper surface.	

Table 2.4: Lead Bullet Corrosion Scale

Grade	Detail Visualised – Lead Bullets	Representative Images
5	• Evidence of Class Characteristics. • Individual Characteristics present. • >25% corrosion formed that does not hinder examination, with limited/no tarnishing present. Majority has untarnished lead surfaces.	
4	• Evidence of all Class Characteristics. • Individual Characteristics present. • 25-50% scaling, corrosion formed that does not hinder identification **OR** • Any amount of scaling, corrosion or discolouration that <u>does not</u> hinder identification.	
3	• Evidence of Class Characteristics • Some evidence of Individual Characteristics, however insufficient to form identification. • 50-75% corrosion, tarnishing or scaling hindering identification. • Some regions of untarnished lead	
2	• Evidence of Class Characteristics (discernible). • Little evidence of Individual Characteristics. • 75-100% coverage of corrosion, tarnishing, oxide or scaling on surface. (Image James, J. 2023)	
1	• Some evidence of Class Characteristics. • No evidence of Individual Characteristics. • ~100% heavy corrosion, tarnishing, oxide or scaling on surface. Representative image of lead bullet surface (Image from Smith *et al*, 1993)	

Table 2.5: Copper Bullet Colour Scale

Grade	Detail Visualised – Copper Bullets	Representative Images
5	• < 25% black scaling and/or discolouration of copper surface. • Majority has bright, untarnished copper surfaces.	
4	• 25-50% black scaling, and/or 'bright gold' discolouration of surface. • Some untarnished areas.	
3	• 50-75% black scaling or 'dull gold' discolouration of surface. Some untarnished areas. • Limited untarnished areas	
2	• 75-100% coverage of black scale formed including 'dull gold' and/or coloured oxide discolouration of surface. • Minimal/sparse untarnished areas.	
1	• 100% black scale and with total discolouration of copper surface (i.e., dull 'gold' colour)	

Table 2.6: Lead Bullet Colour Scale

Grade	Detail Visualised – Lead Bullets	Representative Images
5	• Limited/no discolouration of present. • Majority has untarnished lead surfaces.	
4	• 25-50% discolouration of lead surface.	
3	• 50-75% discolouration of lead surface.	
2	• 75-100% discolouration of lead surface. (Image James, J. 2023)	
1	• 100% discolouration of lead surface. Representative image of lead bullet surface (Image from Smith et al, 1993)	

Chapter 3: Pilot Study

3.1 Introduction

A pilot study was developed to determine a suitable method of attaching materials to bullets in order to retrieve the sample bullets from a decomposition environment. The pilot study was not designed to produce data to assist with the results of the project, however it was undertaken as a 'practical' exercise only, to determine the survivability of the proposed attachment methods in biological fluid (blood used as a model), although the visual damage to the surface of each bullet was also recorded.

3.2 Bullet attachment type

The bullets that were exposed to the cattle blood in the Schott bottles were maintained in a laboratory fume hood for the length of this pilot study and maintained at room temperature (20-23°C). The bullets were removed from the Schott bottles and the eyelets and attached wires were visually examined. From this initial study, it was determined that there was no difference in the ability of the zinc or brass eyelets to remain attached to the base of the bullet. Further, there was no apparent visual effect on the bullets regardless of which eyelet was used. In terms of the remaining practical phases, it was decided to use the same eyelet for each practical phase, which was often dependent on supplies from the local hardware outlet. Regardless of which eyelet types were available, it was decided that either brass or zinc eyelets would be suitable, and each type would not have any detrimental effect on the bullet or ability to remain attached.

Figure 3.1. A representation of the bullet attachment method using metallic eyelet, wire and identifying keyring.

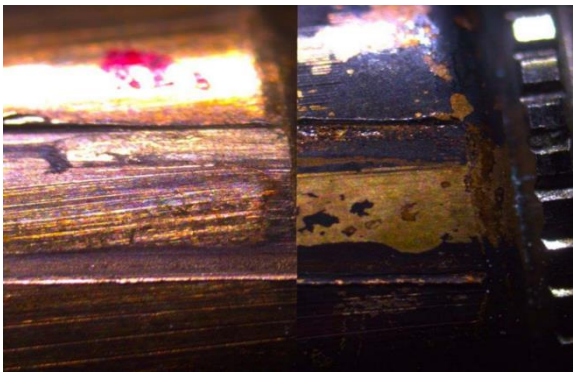
For this phase of the study, zinc eyelets and bare zinc wire was one combination used, and brass eyelets and polymer-coated wire was the other combination used. In terms of the wire attached to the eyelets, it was noted that the wire without the plastic coating did tend to become twisted and tangle easily, even when placed in a Schott bottle. Using only a visual inspection by the naked eye, the bare wire did not appear corrode during this pilot study. The polymer-coated wire was found

to maintain a degree of rigidity and resisted entanglement. It was then decided to use the polymer-coated wire for all future practical and field studies in this project as this wire did not become entangled and would allow for easy removal from subsequent test subjects (pig or human), This polymer or embedded wire did not appear to be affected by exposure to the cattle blood and biological fluids meaning that it did not degrade and increase the potential of being lost during the study.

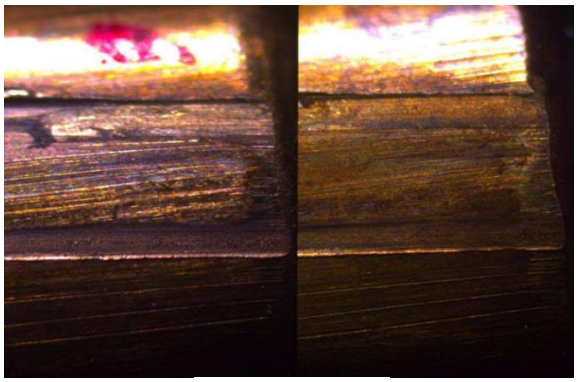
The polymer-coating was also coloured white and proved to be easier to see against the blood. It was assumed at this stage, that this colour difference would assist in locating the wire during the field phases. From this pilot-study, it was determined to use the zinc eyelets and the polymer-coated picture framing wire for future field studies.

3.3 Visual – bullet damage

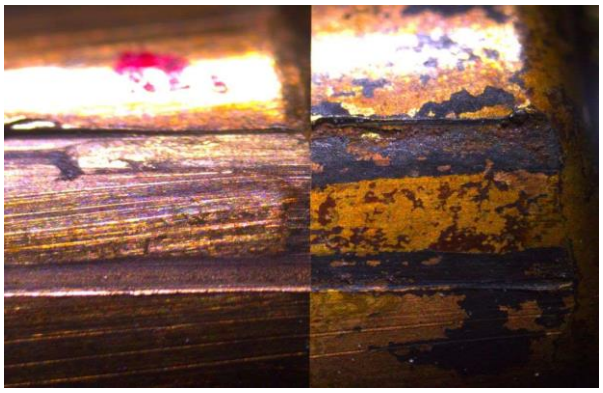
At the conclusion of each week, two bullets were removed, cleaned and a microscopic examination of the respective surfaces was undertaken. The bullet's surface took on a dull gold appearance and black scale formed in the Land Engraved Areas (LEA) at the second week (day 14) and there was loss of striae on the bullets over the final week of the pilot study (day 21).



Figures 3.2(a)



Figures 3.2(b)



Figures 3.2(c)

Figures 3.2. 9mm calibre copper jacketed bullet removed from cattle blood after (a) 7 days, (b) 14 days and (c) 21days.

Some of the gross striae located on the Groove Engraved Areas (GEA) remained, however the identification of the bullets back to the controls became more problematic due to the loss of fine striae, coupled with the obscuration of the striae marks due to the presence of the black scale. This meant, that as time progressed from day 7 to 21, the copper surface of the exposed fired bullets became difficult to identify back to the control bullet, due to the reaction of the blood with the copper surface (Figures 3.2(a) to 3.2(c)). The decrease in the bullet striae could be due to the decreased pH levels of post-mortem blood. Whilst the pH was not directly measured, it has been reported that pH levels decrease due to the accumulation of acidic metabolites, with rat and human blood in vitro decreasing in pH from approximately 7.4 to 7.1 over a four-day period (Donaldson and Lamont, 2013). It is suggested by these authors that the pH in blood stored in vitro reduces at a slower rate than in a decomposing corpse, due to the build-up of other metabolites in the body after death, such as carbon dioxide and lactic acid and the lower levels of stored glucose to fuel anaerobic metabolism (Donaldson and Lamont, 2013).

The metabolites *in vivo* can include lactic acid, which is produced by lactate dehydrogenase via anaerobic glycolysis in red blood cells (Donaldson and Lamont, 2013). According to Donaldson and Lamont (2013), lactate in human blood can increase 20-fold one-hour after death and 50 to 70-fold by 24 hours after death. Another acidic metabolite, formate (methanoic acid), was found in high concentrations in putrefied human blood up to forty-four days after death, where it was suggested that this was caused by the bacterial action on decomposing lipids and proteins (Donaldson and Lamont, 2013). This indicates that the degradation of the copper surfaces may also be attributed to the increasing acidic environment expected in the cattle blood *in vitro*, despite it occurring slower than in a decomposing body (Donaldson and Lamont, 2013), leading to the loss of striae observed at day 21 of the pilot study.

It was observed that the bullets exposed to the cattle blood did appear to have a black scale formed on the surface. The scale, which was not chemically analysed, could be from the production of copper oxide, which may have resulted from the decreasing blood pH to a more acidic environment. Copper (II) oxide is known to be black in colour (Richardson, 2012) and therefore it is speculated that this is the corrosion product seen on these copper bullets. Rao *et al*, (2015), also reported the presence of green-black corrosion products on copper bullets exposed to a decomposing cadaver.

The results from this pilot study were used to inform the methods by which the bullets could be retrieved from the decomposing bodies, by the drilling of small holes in the base of each bullet and attaching metallic eyelets and wire to these bullets for later retrieval. This study along with

the literature review of previous studies (Rao *et al,* 2015), also informed the methodology for exposure time. It was decided that a three-day recovery period was suitable, as used by Rao *et al* (2015). Finally, from this initial study, it was determined that there was no difference in the ability of the zinc or brass eyelets to remain attached to the base of the bullet during exposure to blood, however the polymer coated wire was found to be more resistant to tangling and was a better choice of wire.

This pilot study was conducted in a single biological medium, being cattle blood, which had previously been undertaken by Love, 1980. Therefore, at the conclusion of this pilot study, it was decided that field-based studies in a decomposition environment would be beneficial to understanding any effects that decomposition processes may have on fired bullet striae, due to the complex nature of cadaver decomposition.

Chapter 4: Bullet Damage in Cool Climates

4.1 Meteorological data

The Hawkesbury region generally has cool winters, although it is acknowledged that the conditions are not as cool or cold as other regions around the world, such as the taphonomy research facility at the University of Quebec in Trois-Rivières, Canada (Contenta, 2019). Data supplied by the Bureau of Meteorology (BoM) from the University of Western Sydney Richmond Campus shows an average winter (June to August) temperature range from 12°C to 18°C. Rainfall averages approximately 49 mm per month in winter. The meteorological data was sourced using the Bureau of Meteorology (BoM) website which recorded data from the weather station at the Royal Australian Air Force (RAAF) Base, Richmond, New South Wales (BoM, 2022). The data shows the mean minimum and maximum temperatures (^{O}C), and the two relative humidity recordings (%) taken twice a day at 0900hour and 1500hour during the respective study periods. The data during the study periods are detailed in Table 4.1.

Table 4.1: Meteorological data – cool climate trial. Royal Australian Air Force (RAAF) Base Richmond, New South Wales (BoM, 2022)

Study	Months	Mean minimum Temp (^{O}C)	Mean maximum Temp (^{O}C)	Mean relative humidity (%) (0900hr)	Mean relative humidity (%) (1500hr)
Pig 1	April/May (Autumn)	9.5	22.4	82.8	48.1
Human Donor 1	July/August (Winter)	4.2	17.6	90.9	62.1

4.2 Visual decomposition

The visual decomposition of the first pig in autumn indicated a faster rate of decomposition for the pig compared to the human donor in winter (Figure 3.1). This is likely due to the differences in their respective starting dates, with the Pig 1 study conducted over April and May and the Human 1 study conducted over July and August, as temperature plays an important role in the overall decomposition rate (Mann *et al.,* 1990; Goff, M.L., 2010; Iqbal *et al.,* 2018; Gill-King, H., 2016); colder temperatures are known to decrease the rate of decomposition (Mann *et al* 1990). The slow rate may also be attributed to the biological differences between pig and humans, such as the distribution of body weight and degree of insect activity, rather than environmental variables, as the remains were placed in the same relative location (Knobel, *et al*, 2018). This was further demonstrated by the greater tissue loss in the pig, compared to the human. At the first bullet recovery from the pig, three-days after insertion, the pig had rolled onto its left side and the organs were beginning to protrude from the carcass. There was also a large degree of insect activity. The

pig was repositioned onto its back at the end of the bullet retrievals. From the insertion to day 6, the pig continued to bloat, with the organs protruding from the incisions made into the chest (lungs) and abdomen and maggot activity increased. Studies by Iqbal, *et al,* 2018, describe the bloat stage as being from three to ten days since death, where purging has been observed, which is consistent with the observations in this study. The bloating had decreased by day 9 after the insertion of the bullets and by day 12, the pig appeared to be desiccated. By the last bullet removal day (day 21), the pig appeared to be in the advanced decomposition stages, with dried tissue and skin present over the entire carcass, and the presence of rib bones was only seen by looking into the chest incision sites; no other skeletal elements could be seen. These observations are also supported by the advanced decomposition stage observations made by Iqbal *et al*, (2018). Iqbal describes the advanced decomposition as dehydration of the corpse, and the presence of skin, hair, and bone, with minimal flesh (Iqbal et al, 2018).

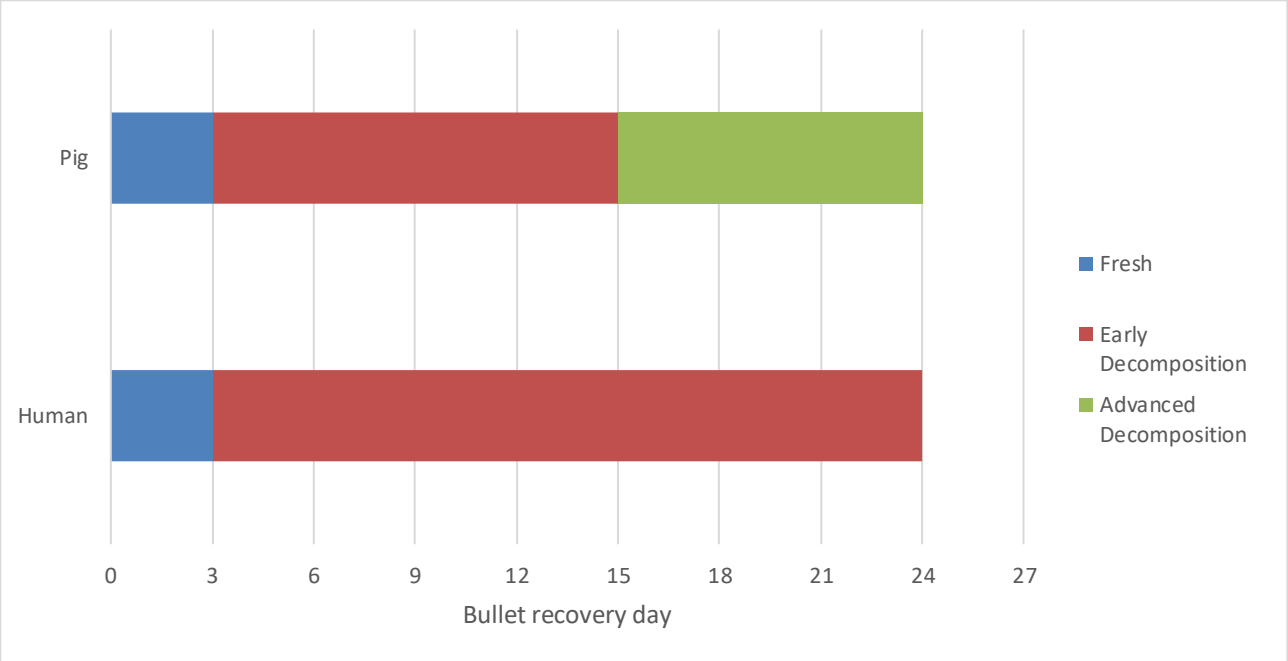


Figure 4.1: Observed decomposition stages – Cool Conditions.

The decomposition of the human donor was slower than that of the pig. As noted on the initial sampling day there was limited insect activity and the donor appeared to be in the Fresh stage (Galloway, 1997). On day nine, decomposition to the abdomen was very limited visually and some grey-green coloured discolouration was observed around the neck and mouth. On day 12, the decomposition around the face and mouth had proceeded to some skin slippage and apparent loss of the eyes; insect activity had become more noticeable with maggots around the abdomen incisions, although only a slight green discolouration near the lower abdomen was noticed. By the last sample day (day 21), the entire trunk was a grey-green colour, with further decomposition to the face, mouth, and neck. No bloating was observed during the decomposition stages. As

previously described, the 'bloat' stage is incorporated under 'early decomposition' and not a separate stage, as described by Iqbal, *et al*, 2018. The slower decomposition rates in cooler conditions could mean that the generation of organic acids and gases are hindered. It is speculated, that the initial decomposition stages of both pig and human in these cooler conditions would not have affected the bullet surface via corrosion due to the relatively slow formation of the organic acids (e.g., lactic acid) and gases (e.g., hydrogen sulfide) in the anaerobic environment (Carter, *et al,* 2007).

4.3 9mm Parabellum calibre copper FMJ bullets

4.3.1 Microscopy Results

The test fired bullets for this stage were discharged in a 9mm Parabellum calibre Norinco model NP22, with conventional rifling. The bullet samples recovered from the pig carcass in autumn were examined by the area of recovery, with the time of recovery from the pig being unknown to the examiners. The results determined by the examiners, using the AFTE Range of Conclusions, from the combined microscopic analysis of the 9mm Parabellum calibre copper FMJ bullets (Figures 4.2(a) and 4.2(b) and Figures 4.3(a) and 4.3(b)) show that there was a minor decrease in microscopic scores as the exposure time to the decomposition process increased for the target organs (Figure 4.4). This indicated that as time of exposure increased, the ability to identify an exposed bullet to the control bullet became more difficult, as the bullet striae detail was being lost. Leading to more inconclusive results being reported. This decrease could be due to the microbial activity and chemical changes that occur in a decomposing body, which when interacting with the bullet causes damage to the surface. For example, leg muscle produces several acids and sulphur containing compounds (Dent et al, 2003) that degrade into aldehydes and ketones (Dent et al, 2003) over time due to the higher protein content in muscles. The acidic environment may contribute to the surface corrosion of the copper bullets, and aldehydes are known to reduce copper (II) to copper (I) oxide precipitates (Clark, 2019), which may be the mechanism by which the copper jacketed bullets in this environment can degrade. The colour of copper (I) oxide is generally red, whereas copper (II) oxides produce a black colour (Richardson, 2002); therefore, it can be speculated without undertaking any chemical analysis, that the black discolouration of the copper bullets is a result of the formation of copper (II) oxide. Rao, *et al*, (2015) reported that green-black corrosive products were also observed on the bullets examined after exposure to the decomposing cadaver (Rao, *et al,* 2015).

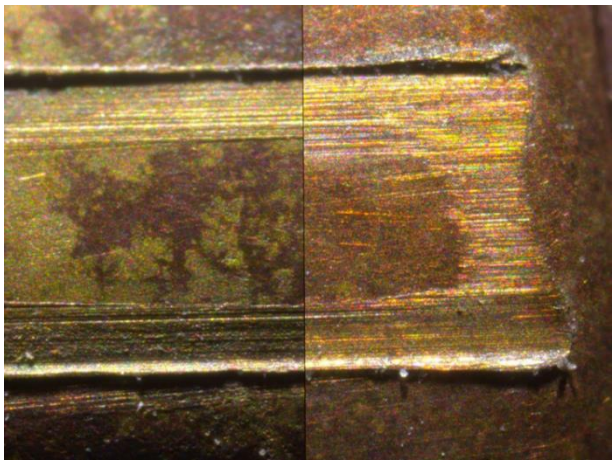


Figure 4.2(a):

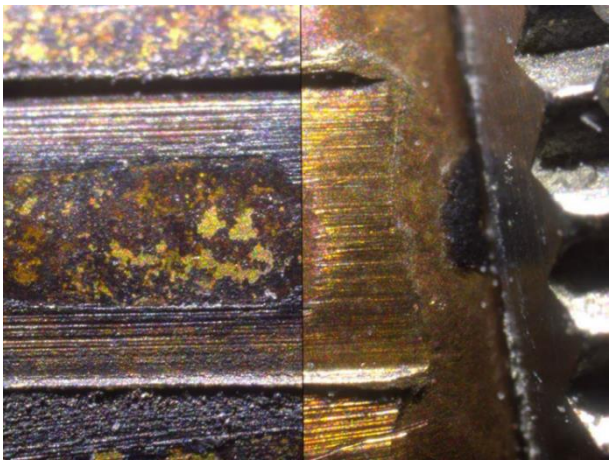


Figure 4.2(b)

Figure 4.2: 9mm calibre copper jacketed bullet removed from the (a) pig carcass leg and lungs and (b) pig carcass muscle.

Figure 4.3(a):

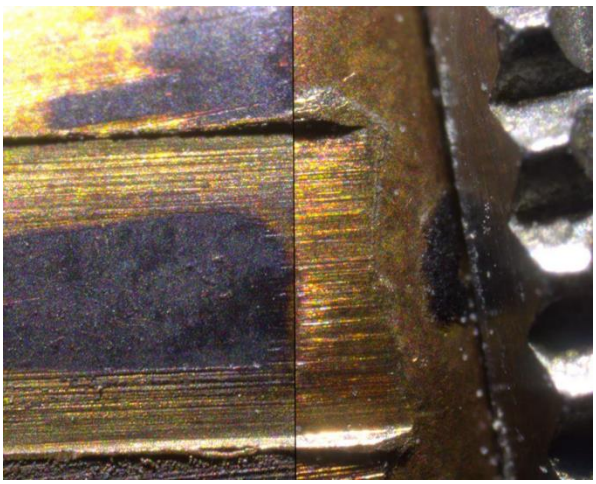


Figure 4.3(b):

Figure 4.3: 9mm calibre copper jacketed bullet removed from the (a) human donor lungs and (b) human donor abdomen.

Whilst there is not a specific time when the microscopic scores all decrease, which would indicate a point when successfully identifying exposed bullets to known samples is not possible, a bullet exposed to soft tissue and organs undergoing decomposition will lose surface features required to make successful identifications as exposure time increases. However, when the microscopic analysis scores were adjusted using median scores (Figure 4.4), there were only two instances where the scores differed (from 2 to 1), indicating that these *Abdomen* scores at days 12 and 21 showed a higher number of inconclusive results. There was also a slight change in the *Muscle*

results, where the microscopic score went down to one (1), indicating slightly more inconclusive results on the last sample day (day 21).

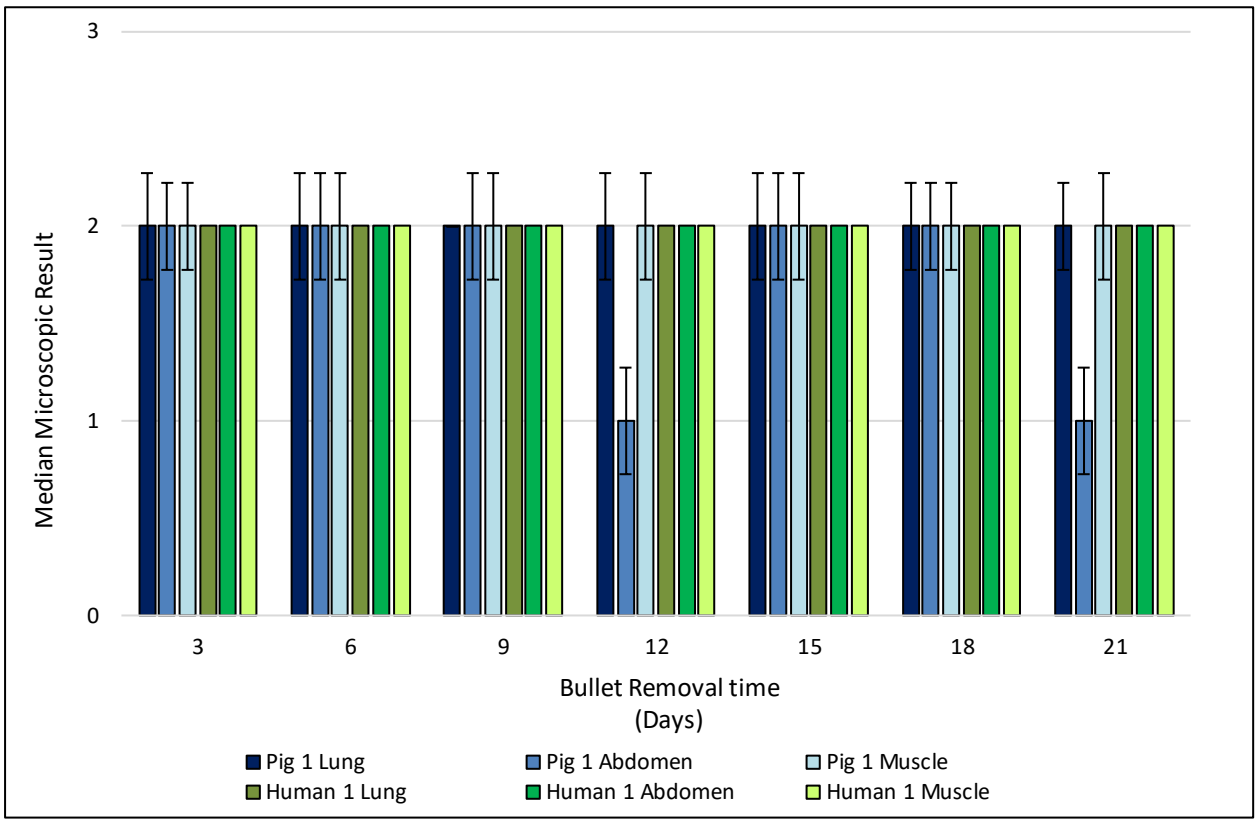


Figure 4.4: 9mm Parabellum calibre copper FMJ Microscopic Results for Pig 1 and Human 1. Error bar represents n = 5 examiners

The median microscopic scores for the *Abdomen* region are slightly irregular and do not follow a steady trend in microscopic examination scores as exposure time increases. This may be due to the different decomposition rates of the abdominal tissue, microbial and chemical activity compared to the *Lungs and Muscles*, leading to a more complex environment in the abdominal cavity. It could therefore be possible, that identifying a bullet from the abdomen may be slightly more difficult as time increases.

The bullet samples recovered from the human donor were examined by the area of recovery, being the lungs, the abdomen, and the muscles. The results of the microscopic examinations of the 9mm Parabellum calibre bullets revealed that all examiners were able to identify all bullets recovered during the decomposition period and from the three areas of the cadaver. As the bullets were able to be identified, it is speculated that this was due to the slower decomposition rate of the human in cooler conditions and the subsequent reduced generation of decomposition chemical species. It is speculated, that the reduced decomposition stages of the human during winter would not have affected the bullet surface via corrosion due to the relatively slow formation of the organic acids (e.g., lactic acid) and gases (e.g., hydrogen sulfide) in the anaerobic environment (Carter, *et al,* 2007).

4.3.2 Corrosion Results

The copper jacketed bullets from the pig underwent corrosion that involved a dulling of the surface of the copper, to produce a dull-gold colour (Figure 4.5). Other corrosion features included the presence of black scaling and blue or red coating on the bullet surface. The corrosion of copper is a relatively well-known phenomenon; however, the chemical products of decomposition are numerous and complex. Carter *et al,* 2007, Dent *et al,* 2003 and Vass *et al*, 2002, have described several chemical compounds produced by the anaerobic processes involving various microorganisms and the internal cellular processes of the body, resulting in the transformation of proteins, fats (lipids) and carbohydrates into several organic acids and gases. Further decomposition can reintroduce oxygen into the body, which can lead to other chemicals being produced; a total of fifty-six (56) compounds have been associated with human decomposition during one study (Iqbal, *et al*, 2018).

The production of copper oxide to yield the black, blue-green, or red coating (Richardson, 2002) seen on some of the recovered bullets could be the result of the reaction between copper and acetic acid (Vass, *et al*, 2002) which is formed in anaerobic conditions during carbohydrate decomposition. This may also occur through the reaction of copper with ketones and aldehydes that are produced when fats in the body are hydrolysed to fatty acids, which are then oxidised to aldehydes or ketones (Dent *et al,* 2003).

Figure 4.5: 9mm Parabellum calibre bullets recovered from Pig, indicating the corrosion products (left to right):

- *Gold with some black scaling (L).*
- *Untarnished copper – Control bullet (C)*

This corrosion scale was produced as it may be useful in attempting to determine length of exposure (in terms of time) for copper jacketed bullets recovered from a decomposing cadaver. The corrosion scores for the 9mm Parabellum calibre copper FMJ bullets (Figure 4.6) showed that with the pig *Lungs and Muscle*, there are steady corrosion scores as the exposure time to the decomposition process increases, where a high score indicates increased corrosion of the surface i.e., the higher the score, the more surface corrosion. In terms of the results for *Muscle,* this could be due to the decomposition of proteins, which do not occur at uniform rates (Dent, *et al,*2003). Proteins are broken down by a process known as proteolysis, however neuronal and epithelial

tissue proteins are broken down first, whilst skeletal muscle proteins are some of the proteins that are more resistant to decomposition (Dent, *et al,*2003). The sulphur containing amino acids in proteins are degraded by microbial action to hydrogen sulfide, ammonia, and organic acids. This slower breakdown of skeletal muscle protein and an environment less complex than the abdomen and lungs may be the factor why the results for *Muscle* produce steadier corrosion scores. The chemical changes that occur in the leg muscle over time or the ability of the copper to produce a protective layer on its surface, may have a role in protecting the underlying metal.

There are variations in corrosion scores associated with the pig *Abdomen* as exposure time increases (Figure 4.6). This goes against the corrosion scores noted with the *Lung* and *Muscle*. As stated above, this may be due to the decomposition rates and chemical activity in the *Abdomen,* although a general decline in scores (increased corrosion) is noted in Figure 4.6 across all tissue types. For identification purposes, this meant that identification was possible despite the observed corrosion on the bullet samples. The pig *Abdomen* scores in Figure 4.4 demonstrated a higher variability however, identification was still possible for bullets recovered within the timeframes of this trial. The two variations in microscopic identifications for the pig *Abdomen* (Figure 3.2) occurred on days 12 and 21, yet the corrosion scores were the same on both days (an assessed corrosion score of three – Figure 4.6); therefore, the variations in microscopic identifications may not be related to corrosion mechanisms in this instance. It may be possible that the differences in microscopic identification could be due to other factors such as the marks from the firearm's barrel not being transferred to these two bullets.

The variations in corrosion scores for the *Abdomen* samples could be due to a complex decomposition environment with the higher microbial population in the gut and the presence of gastric acids and lipids. There were not the variations in the corrosion scores noted in the *Lung*, which could be due to a relatively stable environment. Despite a study conducted by Vass, *et al* (2002), where it was noted that the lung tissue degraded too rapidly and contained too large a microbial population to be useful for that study and was subsequently dropped, the microscopic identification results for *Lungs* in cool conditions during this project were not affected by this *Lung* environment as reported by Vass *et al* (2002), The gradual declining corrosion scores for both pig and human *Lungs* in this study indicated a general increase in corrosion on the bullet's surface and possibly a more stable environment in this instance compared to that experienced by Vass *et al* (2002).

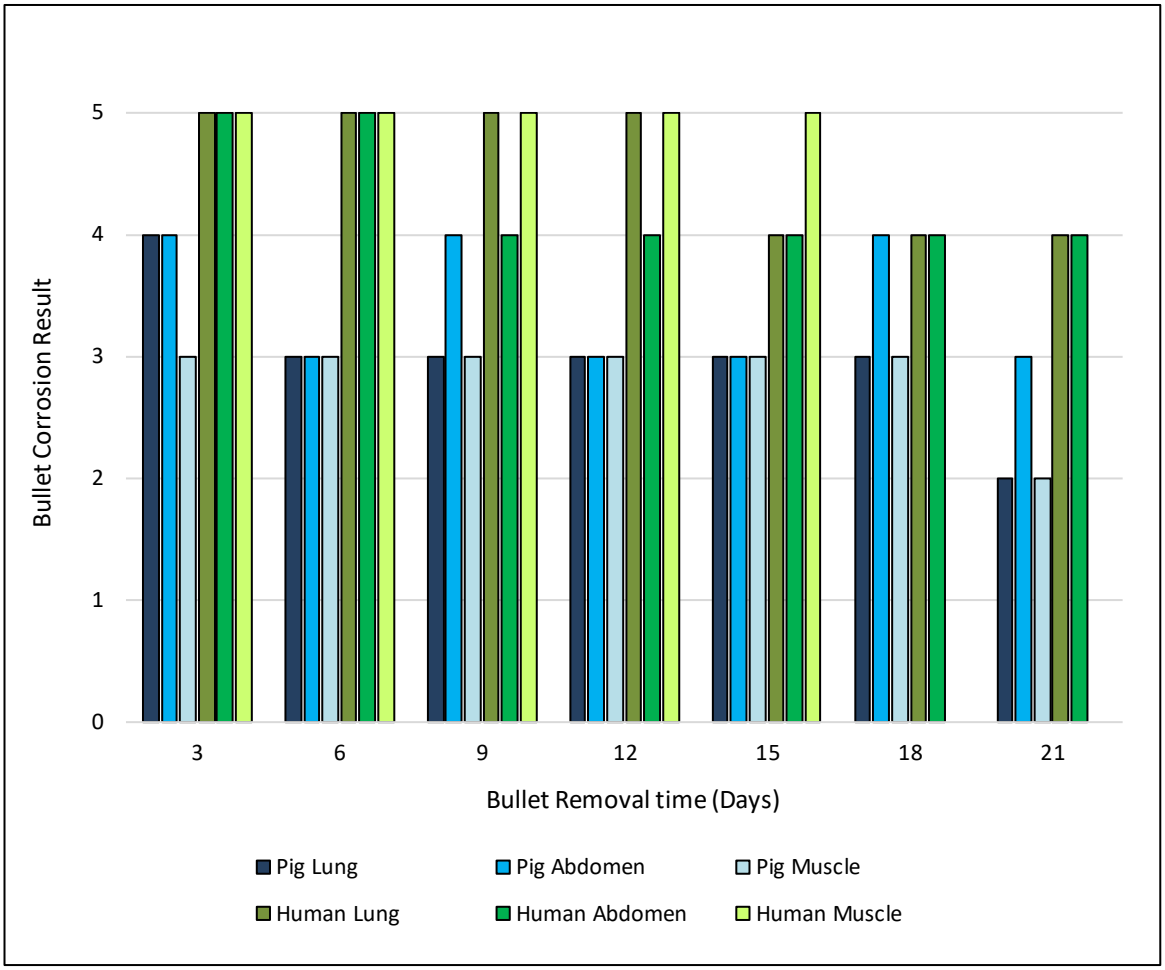


Figure 4.6: 9mm Parabellum calibre copper FMJ Corrosion Scores for Pig 1 and Human 1

The pig *Muscles* did commence with a mid-level corrosion score that remained stable for the remainder until the last sample day of the exposure period. Therefore, using this scale, it may be difficult to determine an approximate decomposition stage for bullets recovered from leg muscle, given that the bullets recovered showed relatively stable corrosion for the entire test period. The relatively steady corrosion mechanism experienced in *Muscles*, may be due to a less complex decomposition environment and a higher protein content in muscles, which produces several acids and sulphur containing compounds (Dent *et al,* 2003) that degrade into aldehydes and ketones (Dent *et al,* 2003) without the high microbial population of the *Lungs* and *Abdomen*.

Possible corrosion mechanisms may involve the reaction of the copper with sulphur-containing by-products of the microbial decomposition of certain amino acids in proteins, such as cysteine and cystine (Dent *et al*, 2003). These amino acids can be broken down to hydrogen sulfide gas, thiols, and ammonia. The black scaling seen on the bullets, whilst not verified instrumentally, is postulated to be copper sulfide, resulting from the reaction between copper and hydrogen sulfide. Other chemical and microbial-related corrosion mechanisms that have been identified in copper pipes used for household and commercial water supply (Vargas, *et al,* 2017) and in metallic

prothesis, although not related to copper (Beech, *et al*, 2006), may be of some usefulness in understanding the corrosion mechanisms in this study.

Vargas, *et al* (2007) described the tendency for copper to react with dissolved oxygen, forming cuprite (Cu_2O) as a primary solid corrosion by-product. This leads to the formation of a 'duplex film model' which is a two-layer cuprite film containing different cuprite structures (a compact and a porous layer), resulting in varying electrochemical properties of these layers and the corrosion of copper by the formation of copper scales (Vargas, *et al*, 2007). This 'duplex film model' has been described as earlier by Ives and Rawson (1962).

Beech, *et al*, (2006), have described how Microbially-Induced Corrosion (MIC) occurs in metal and alloy implants, which by extension could involve the MIC of copper in decomposing cadavers. Beech, *et al*, (2006) describes how bacteria from the genus *Pseudomonas, E. Coli, Staphylococci* and *Streptococci* and fungi of the *Candida* genus all produce biofilms that can have a role in MIC, due to the metabolic activities producing organic and inorganic acids, hydrogen sulphides and ammonia (Beech, *et al*, 2006), all of which may have a role in the corrosion of the copper bullet surface. Rao *et al* (2015), hypothesised that the copper bullets used in that study were affected by the formation of biofilms that altered the electrochemical processes on the copper bullet's surface, leading to the corrosion observed, after exposure to the decomposing cadaver.

To ascertain if there was a point on the corrosion scale where fewer microscopic identifications were made and therefore a point where identifications were less likely, the total number of microscopic results (scores) made by the examiners, against corrosion scores for the pig were combined and graphed. The results indicate that as the corrosion becomes less pronounced (i.e., higher score) the percentage of microscopic identification scores increased (Figure 4.7), meaning that more identifications were made. Conversely, the number of inconclusive results increases as the corrosion scores decrease (more corrosion), which indicates that increased corrosion affects the microscopic striae and the examiner's ability to identify bullets to a known source.

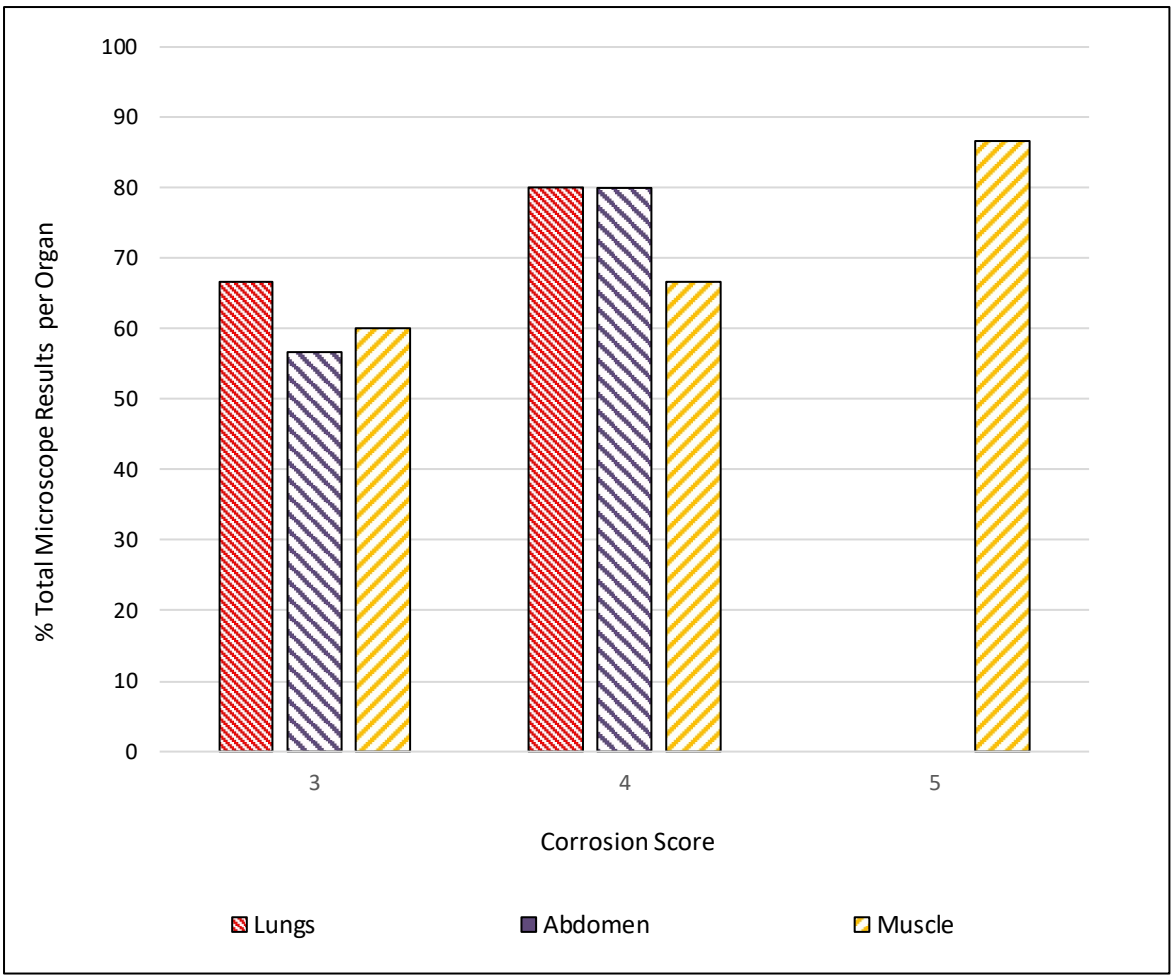


Figure 4.7: Percentage of Identification Results versus Corrosion Scores for Pig 1.

The result for *Lungs* and *Abdomen* between corrosion scores three and four indicates that the microscopic identification results increase. Between corrosion scores three and five, the trend with *Muscle* is seen as the microscopic identification results increase with higher scores (less corrosion).

The bullets from the human could all be identified to a common source, and the decomposition of the donor was not as pronounced as the pig carcasses, however, there was some corrosion that did occur to the exposed fired bullets. The human *Lung* and *Abdomen* bullets did experience a steady incline in corrosion scores, as exposure time increased, and they did not display the variations in corrosion scores as seen with Pig 1 sample bullets. The *Abdomen* bullets appeared to decrease in corrosion (higher score) at day 9, whilst the bullets from *Lungs* did not corrode noticeably until Advanced Decomposition; both bullet samples then remained steady for the last two recovery days respectively. The factors that may have played a role in the decreased corrosion at day 9 for the human Abdomen could be due to the placement of the bullet within the abdomen, a change in the specific location of the abdomen where this bullet was located or the bullet's surface; however, these are all speculative and could be subject to further research.

The bullets recovered from the *Muscle* tissue did not undergo any appreciable corrosion and the score remained steady throughout this part of the study, albeit two of the final bullets that were not recovered from the human due to the bullets being lost within the cadaver during collection, due to the wire becoming entangled on an internal bone or tissue of the cadaver and the eyelet being pulled from the bullet. The use of a metal detector may have alleviated this issue, however, was not employed during the retrieval stage. The corrosion changes in the *Lung* and *Abdomen*, which was not observed with the *Muscle* bullets, could be attributed to the appearance of grey-green discolouration and skin slippage around the face, neck, and trunk, whilst the legs did not visually undergo such decomposition stages during the same period (Figure 4.1). The *Lung* and *Abdomen* did undergo the chemical and microbial changes discussed and therefore corroded the bullets to some extent the *Muscles* did not undergo these processes to a sufficient degree during this time to affect the copper jacket surface.

Unlike the analysis for the pig, all bullets exposed to the human were identified to a common source and regardless of the corrosion state, all identifications were possible. As with the microscopic results previously discussed, this is likely due to the slower decomposition experienced by the human compared to the pig, although the actual reason is uncertain. Despite the resulting limited data from utilising one human and all the recovered copper bullets being identified to the control during the microscopic analysis, the examination of the 9mm Parabellum calibre copper fired FMJ bullets, minimal corrosion took place. The identification of all recovered bullets to the control, should indicate minimal or non-existent corrosion, however this was not the case, because there was some corrosion that took place on the copper bullets in the cool conditions, although not enough to hinder identification of the recovered bullets to a common source. These bullets were subjected to the same assessment regarding the corrosion scores, as was undertaken with the 9mm Parabellum calibre copper FMJ bullets removed from the pig and highlighted in Figures 3.4. When comparing the microscopic identification and corrosion scores, there are instances where the pig and human corrosion scores were the same and identifications were possible at the same time periods (day 18 indicating early and advanced decomposition respectively), which may indicate a correlation between corrosion levels and the presence of striae on the fired bullet, sufficient for an identification to the control bullet. In this instance, bullet corrosion scores of four (4) were assessed for pig *Abdomen* and Human *Lung* and *Abdomen* and all these sample bullets were identified to a common source. However, there are two instances where the median microscopic scores indicate inconclusive results; although these are accompanied by the same corrosion scores (i.e., pig *Abdomen* results for days 12 and 21 at the Advanced Decomposition stage).

It is also noted that at day 12 and 15, the three pig corrosion scores for each sample area (being the *Lungs, Abdomen* and *Muscle*), are the same, each with a corrosion score of three, yet the *Abdomen* was inconclusive, whilst the pig *Lungs* and *Muscle* were identified. On day 21 (Advanced Decomposition), the assessed corrosion scores for the pig *Lungs* and *Muscle* indicated higher surface corrosion yet were both microscopically identified to a common source; the pig *Abdomen* had a higher corrosion score (less surface corrosion) yet was assessed microscopically as inconclusive. During the Advanced Decomposition stages, it may be possible to conclude from these results that the correlation between microscopic identification and corrosion scores does not correlate as readily as during the Fresh and Early Decomposition stages. It could be that the formation of the decomposition chemical species in the earlier decomposition stages affect the bullet, whereas when decomposition becomes more advanced, other factors may play a role in corrosion, such as the reintroduction of atmospheric oxygen or altered microbial populations. This is possibly an area for future study. Rao, *et al,* 2015, described the loss of striae on the recovered bullets due to corrosion after eight days of exposure, and total loss of striae (individual characteristics) after ten days. Rao *et al* (2015) also goes on to state that there is a direct correlation between corrosion and obscuration of the bullet striae, which was noted in some instances involving the pig during this project.

4.3.3 Colour Scale Results

It was observed during the recovery days that the bullets removed had undergone a change in colour from the untarnished copper colour to a series of black and gold (dull and bright) colours (Figure 4.8). This resulted in the development of a colour score (Table 2.5 and 2.6) that was derived as a second means of possibly determining the length of bullet exposure based on colour.

Figure 4.8: 9mm Parabellum calibre bullets recovered from Pig 1, indicating the following colours (left to right): Bright gold with some black scaling (labelled L), dull gold (labelled A), bright gold (labelled M) and untarnished copper, the control bullet (labelled C)

In general, the colour scale developed indicates a relatively untarnished copper (colour score of five) to a bullet which is largely covered by black tarnish (colour score of one), with various shades of bright or dull gold-coloured appearance between these minimum and maximum scores. Therefore, as exposure time to the decomposing body progresses, the copper bullet undergoes

oxidation and reactions with decomposition by-products such as sulphur-containing compounds that changes the appearance from copper through 'bright' gold to a dull gold, or dull gold covered in black scale, meaning a decreased score as the colour change becomes more pronounced. This scale as stated, is subjective and no instrumental analysis of the copper surfaces has been undertaken to determine the exact chemical composition.

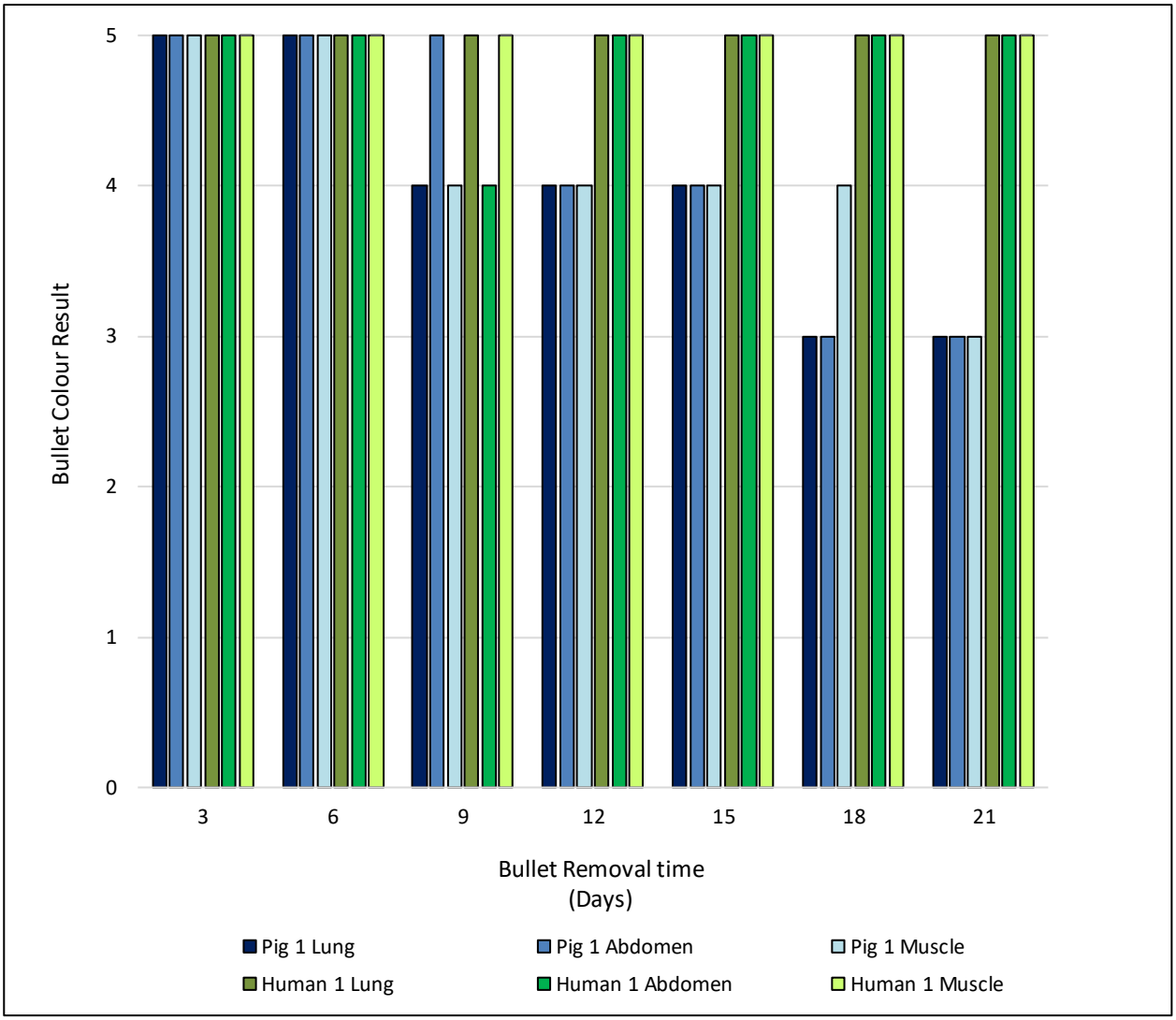


Figure 4.9: 9mm Parabellum calibre combined bullet colour scores for Pig 1 and Human 1

On day 18, there was a decrease in colour values for the pig *Lung* and *Abdomen* samples (Figure 4.9), which appears to correlate with a decrease in corrosion scores. The corrosion and colour socres would be related to one another in terms of the surface features of the copper bullets; increased corrosion, could be related to colour changes observed on the bullet's surface, that is due to the accumulation of different corrosion products. This could be ascribed to the bullet having undergone increase changes to their respective surfaces as exposure time increased, where as the colour results for *Muscle* do not experience this change in coloure score until the next sampling period on day 21.

The results represented in Figure 4.9, indicates that as the colour change becomes more pronounced (i.e., higher score) for copper through bright and dull gold to black, there is a noticeable variation in the percentage of microscopic identifications for *Lung* and *Abdomen*. It is possible, that the colour scale may not be suitable for determining a relationship between identifications and inconclusive results. It may be that the colour changes have a variable effect on microscopic identifications and therefore less reliable. The result for *Muscle* does have steady increasing colour scores, which again could be due to the less complex decomposition environment (Figure 4.10).

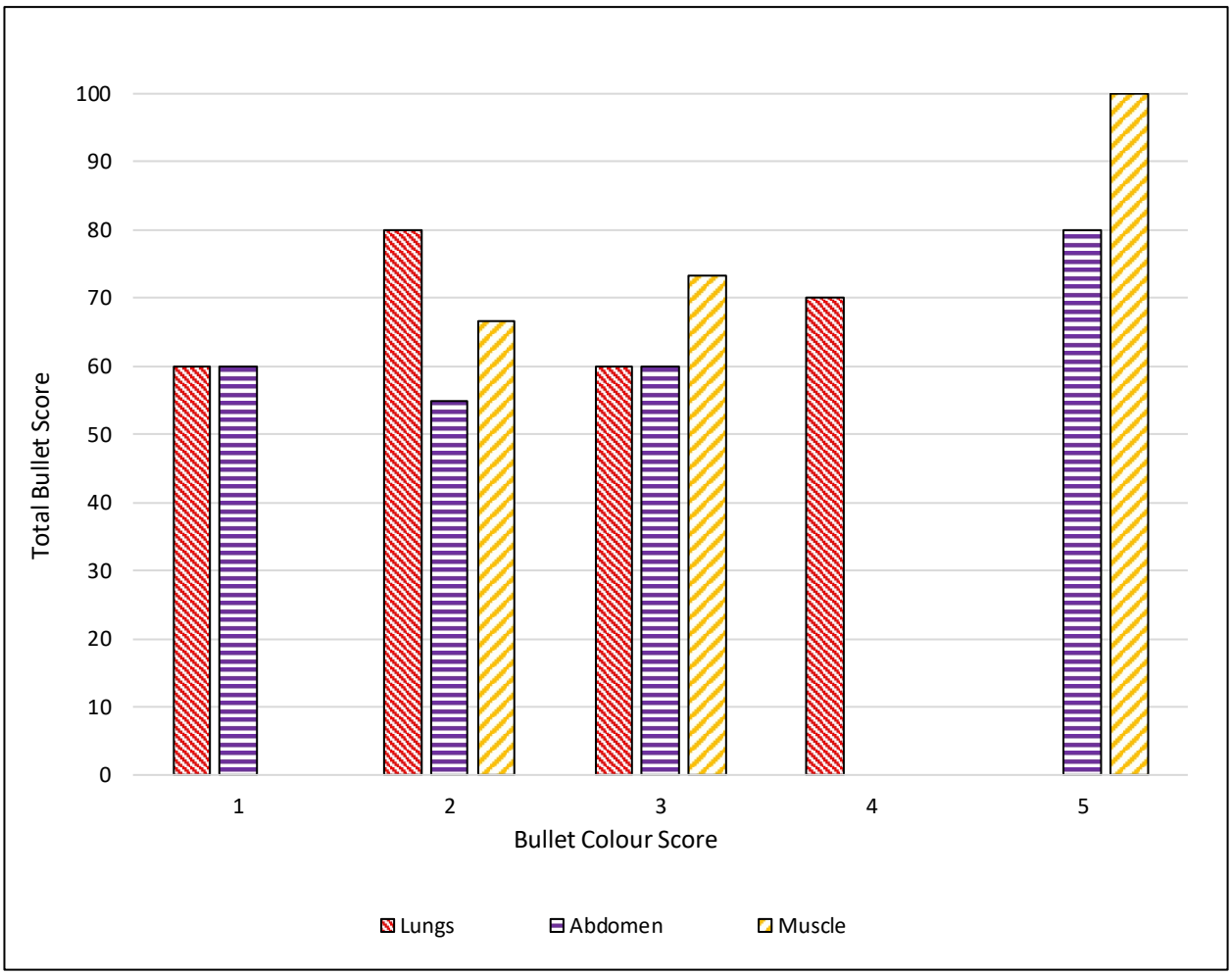


Figure 4.10: Percentage of Identification Results versus Colour Scores for Pig 1

The decomposition of the human donor was not as pronounced as the pig carcasses, however, there were some colour changes that did occur to the fired bullets exposed to the human donor. As the decomposition was less pronounced with the human donor, this resulted in all bullets being positively identified microscopically and therefore no relationship between identification and colour results could be established. This is despite the apparent relationship in the corrosion and colour results observed in Graphs 3.6 and 3.10. The 9mm copper jacketed bullets recovered from

the *Lung* did experience a relatively steady increase in colour scores as exposure time increased, however, they did not display the variations in colour scores as seen with the pig *Lung* sample copper jacketed bullets. The 9mm copper jacketed bullets recovered from the *Abdomen* displayed decreased colour scores between days 9 to 21, with variations between scores 3 and 4 inclusive. The copper jacketed bullets recovered from the *Muscle* did not undergo any appreciable colour change and remained steady throughout this part of the study.

The colour changes in the *Lung and Abdomen*, which was not observed with the *Muscle* bullets, could be attributed to the appearance of grey-green discolouration and other decomposition process that occurred in the cadaver's trunk, but not in the legs, which did not visually undergo such decomposition stages during the same period. The *Lung and Abdomen* did undergo the chemical and microbial changes discussed and therefore corroded the bullets to some extent; the muscles did not undergo these processes to a sufficient degree during this time to affect the copper jacket. It is a matter of conjecture, however, the larger variations seen with the Abdomen bullets could be a result of the complex microbial and chemical changes occurring in the abdominal region.

As with the previous results, the use of this colour scale would need to be approached with caution, when using the results for fired copper jacketed bullets recovered from the abdominal area. However, it could be argued, that any significant change in colour (from score 1 to scores 4/5) could indicate that the copper jacketed bullet has been exposed to the decomposing abdominal tissue for at least nine days. Conversely, the colour changes were not as pronounced for the copper jacketed bullets recovered from human muscle tissue and using this scale, no significant information could be obtained.

4.4 Integrated Ballistic Identification System (IBIS) Results

The Integrated Ballistic Identification System (IBIS) was employed to analyse the 9mm calibre copper jacketed bullets exposed to the decomposing pig in cool conditions. This was restricted to the copper jacketed bullets, due to the number of inconclusive results from the manual microscopic comparison examinations of the lead bullets and the time available on the IBIS system. A high unified score indicates a higher likelihood of the 'exhibit' bullet being identified to the control. The unified score value represents the overall similarity of a correlation result relative to the other results and as such, there is no maximum score available. The MatchPoint+^{TM} system ranked the correlation results according to a unified score for the sample of bullets from the pig in cool conditions (e.g., A2, L2, LH etc.) acquired onto the system. The naming convention for these bullets e.g., A2, L2, LH etc. (Figures 4.11 and 4.12) are related to

the random bullet identifiers given to each recovered bullet. The random identifiers were provided during the microscopic examination phase, so that the examiners did not know in which order the bullets were recovered from the specimens and region, being pig or human and from the respective *Lungs, Abdomen* or *Muscle.* Therefore, bullets designated with L, where recovered from the *Lungs* with a random second character after the L, and where allocated a blue bar in the graph. Bullets designated with A, where recovered from the *Abdomen* with a random second character after the A, and where allocated a yellow bar in the graph. The bullets designated with L, where recovered from the Lungs with a random second character after the L, and where allocated a blue bar in the graph.

Table 4.2: Fired bullet sampling days and bullet engraving for Pig 1 – cool conditions.

Set	Sample day	Bullet type	Engraved label	Comments
1	Day 3	9mm	LT, AT, MT	The bullet type (9mm) in each set were all engraved with the following first letter, which denotes the sample region: L = bullet from area targeting lungs. A = bullet from area targeting abdomen. M = bullet from area targeting leg muscle. The second character was randomly chosen so not to reveal to the examiner the order of bullet removal.
2	Day 6	9mm	L2, A2, M2	
3	Day 9	9mm	LP, AP, MP	
4	Day 12	9mm	LH, AH, MH	
5	Day 15	9mm	L6, A6, M6	
6	Day 18	9mm	LC, AC, MC	

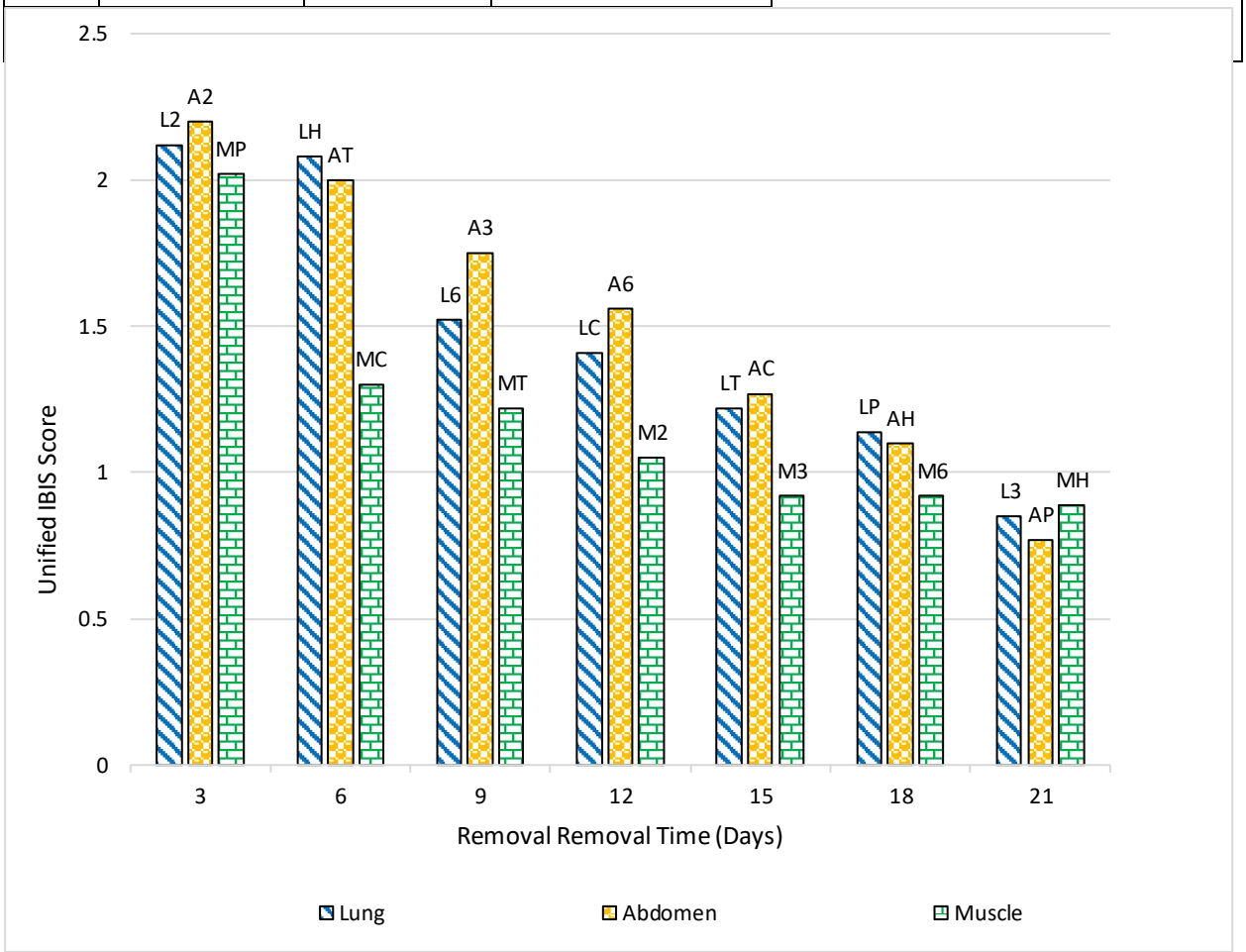


Figure 4.11: Ranked IBIS Correlation Scores for 9mm calibre copper bullets from Pig 1

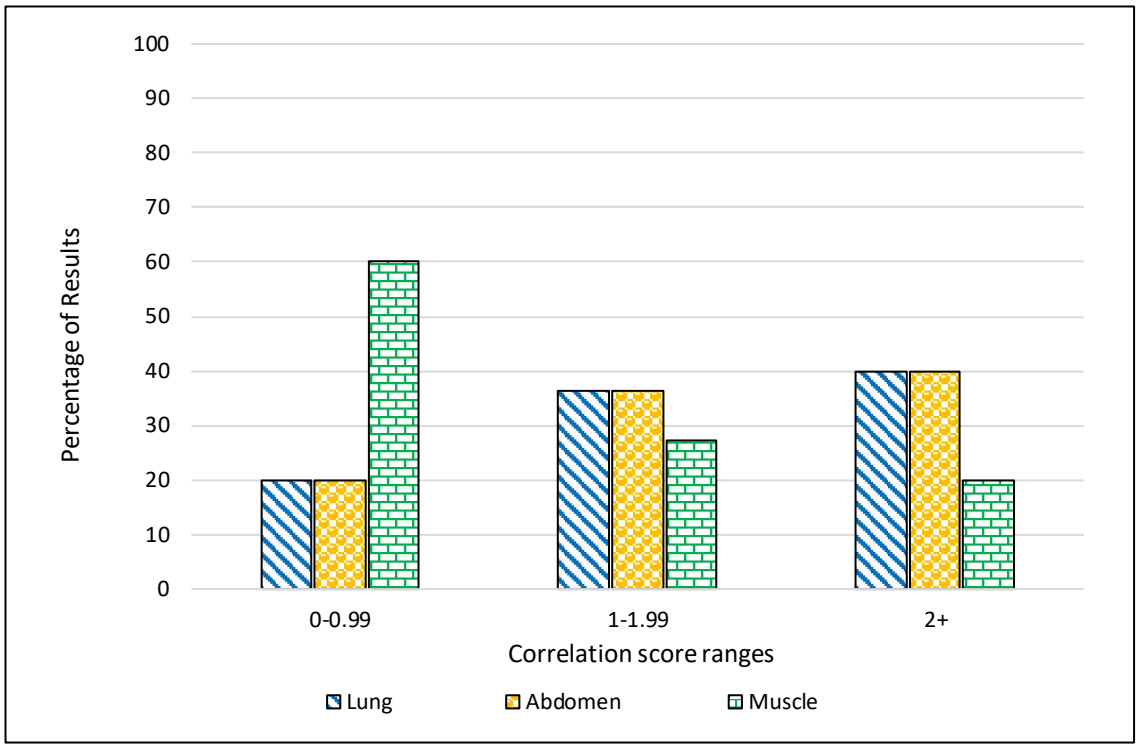


Figure 4.12: Percentage of correlation scores for retrieval areas for 9mm calibre copper bullets from Pig 1.

These correlation results for the bullets retrieved from the pig in cool conditions were then ranked from highest to lowest scores, and graphed according to the region of retrieval, being the *Lungs* (blue), *Abdomen* (yellow), and *Muscle* (green) (Figure 4.11). When the percentage of correlation score ranges per region are plotted, there are more *Lungs* and *Abdomen* results present in the higher correlation scores compared to the *Muscle*, which had its highest representation in the lower correlation scores (0 – 0.99) (Figure 4.12).

From the Figure 4.12, the higher percentage of Muscle scores being in the lowest IBIS correlation range could be due to the relative corrosion levels for the bullet removed from the pig Muscle and the surface features that may have affected the ability of the IBIS system to scan and create the images of these surfaces.

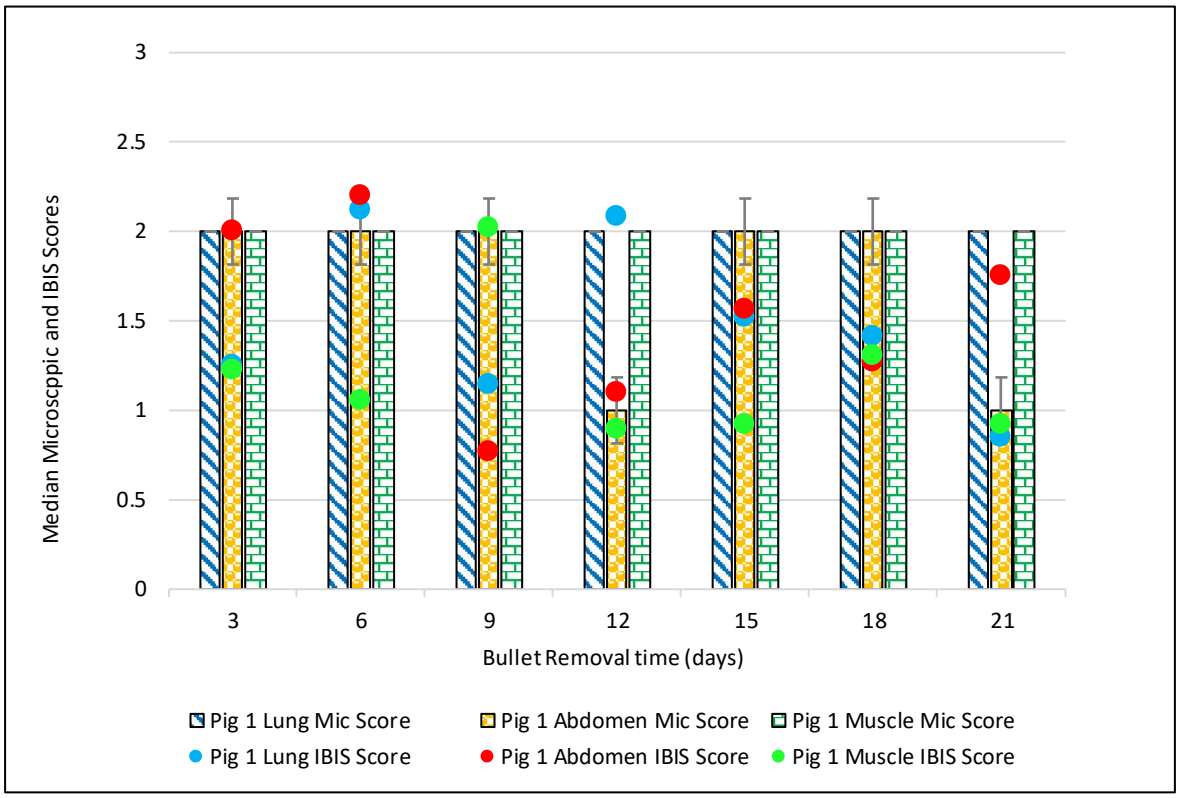


Figure 4.13: Microscopic and IBIS correlation scores for retrieval areas for 9mm calibre copper bullets from Pig 1

When the median microscopic scores (Mic Scores) were plotted with the IBIS correlation scores (IBIS Scores) in Figure 4.13, some of the identifications where the median scores indicated identifications, the IBIS correlation scores were relatively low. This could be due to the relative 'strength' of the correlation score for those bullets versus the control within the group acquired only and not a result of poor marking of the bullet surface. By way of example, the IBIS correlation scores at day 6 for *Lungs* (blue dot) and *Abdomen* (red dot) have produced relatively high scores, compared to the correlation score for *Muscle* (green dot), despite the microscopic results for all areas indicating an identification between the control and exposed bullets. This trend has repeated on other retrieval days, although the 'outlying' IBIS correlation score changes each day between the target areas i.e., the outlying IBIS correlation result on day 12 is the *Lung* (blue dot) result.

4.5 .38 Special Calibre lead bullets

4.5.1 .38 Special calibre Microscopy and Corrosion Results

The test fired bullets were all discharged in a .38 Special calibre Smith & Wesson model 14 revolver, with conventional rifling. A total of five qualified forensic firearm experts participated in the analysis of .38 calibre lead fired bullet samples recovered from the pig and human. Visually it was noted that the recovered lead .38 special fired bullet samples from Pig 1 and Human 1 had

a slight amount of corrosion on the surface. The results indicated a unanimous inconclusive result for all lead .38 Special recovered samples across the entirety of the recovery period and from each recovery location (Figure 4.15). Chow *et al,* 2003, stated that the lead bullet striae were mildly affected during the exposure of these bullets to decomposing pig carcasses, however they were found to be unsuitable for comparison purposes and no conclusions were drawn by the authors regarding the effect of decomposition processes on lead bullets (Chow *et al*, 2003).

Figure 4.14 .38 calibre bullets recovered at day 18 from Pig 1, indicating the 'yellowing' colour (left to right). The Control bullet (C) is on the far right of the image.

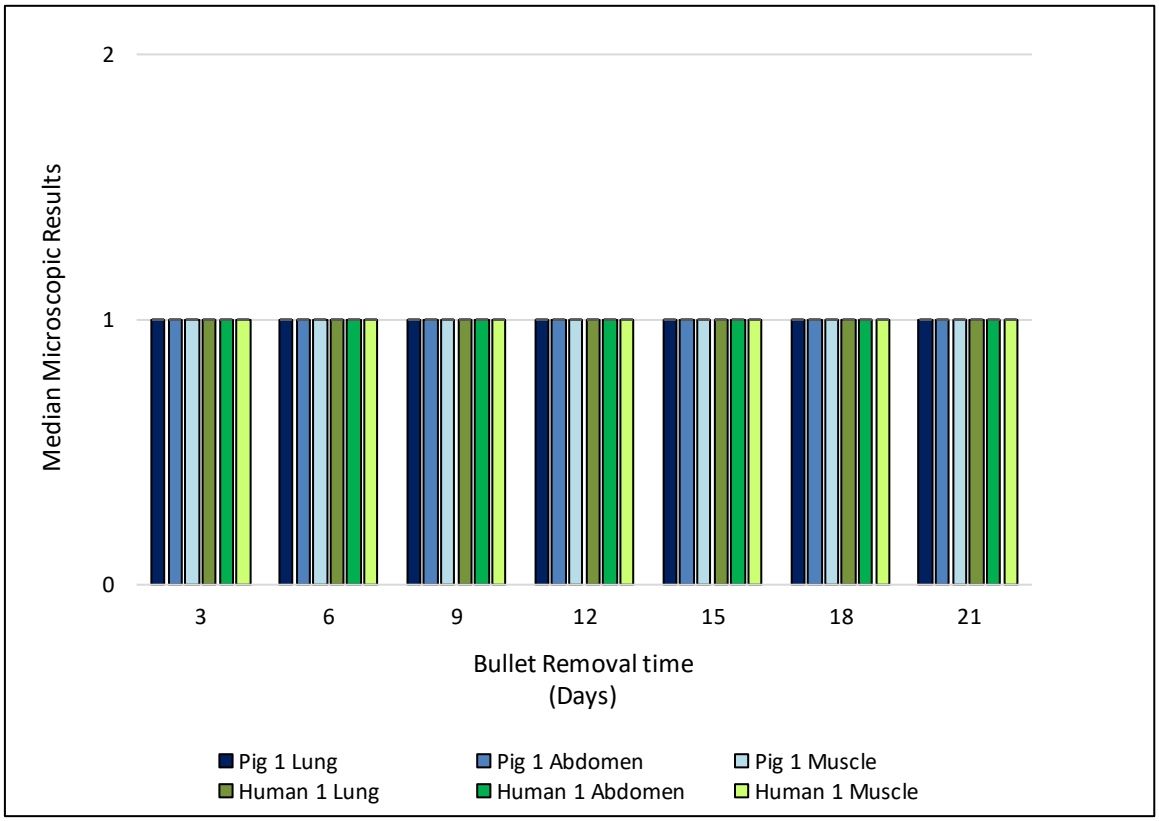
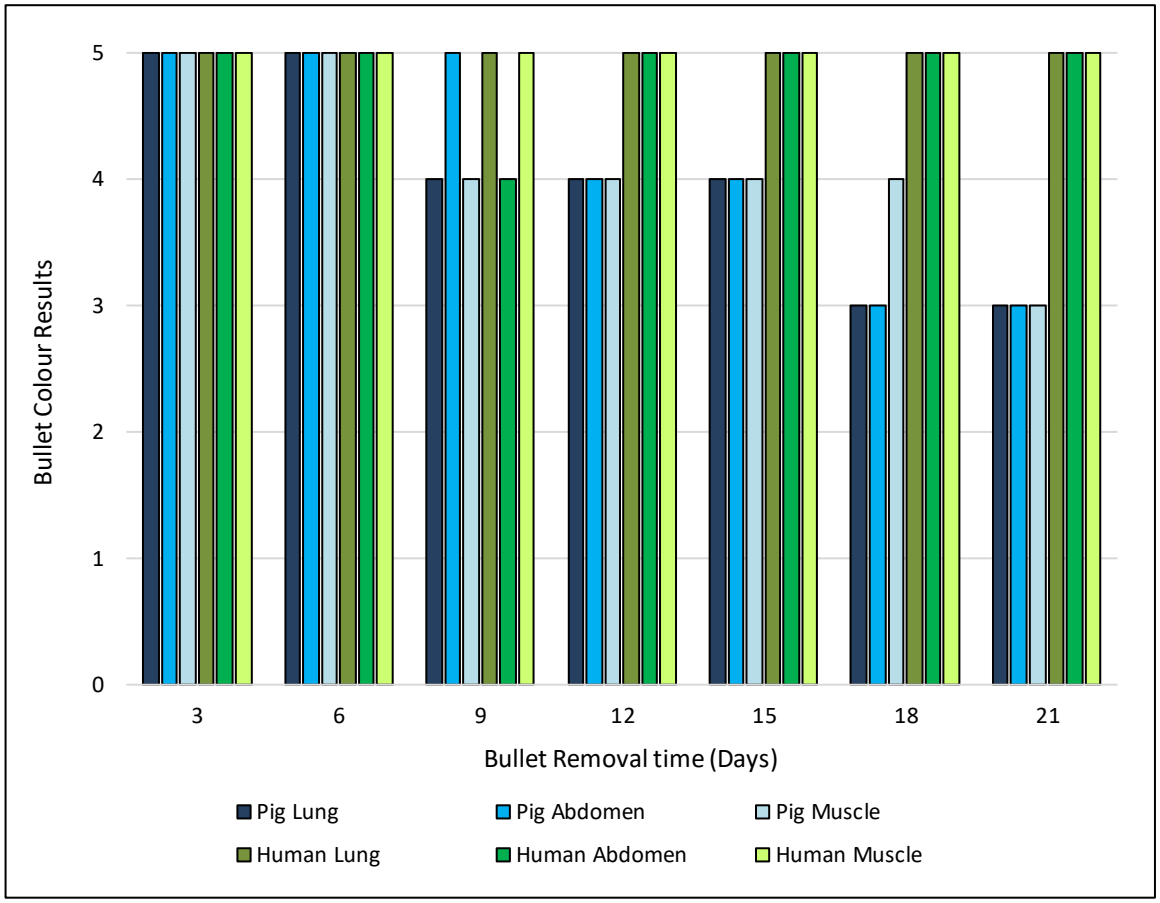


Figure 4.15: .38 calibre lead bullet Microscopic Scores for Pig 1 and Human 1

4.5.2 Colour Scale

The colour results for the .38 calibre LRN pig bullets (Figures 4.16) were subtle and generally confined to a yello*w* or yellow/brown discolouration on the lead bullet's surface. No scaling, as was seen on the 9mm Parabellum calibre copper jacketed bullets was observed on the lead bullets. The colour results for lead also demonstrated an increase in colour scores for *Abdomen* and *Muscle*, unlike those for *Lung*, which indicated one variable result. This differs from the colour results for the 9mm Parabellum calibre copper jacketed pig bullets and due to the relatively inert lead surface, compared to copper. The colour results for the .38 calibre LRN human bullets did not show any discolouration and was confined to a yellow/brown discolouration on the surface of the lead bullets recovered on day 9. No scaling, as was seen on the 9mm Parabellum calibre copper jacketed bullets was observed on the lead bullets. This differs from the colour results for the 9mm Parabellum calibre copper jacketed human bullets, where colour changes were noted for bullets



recovered from the *Lungs* and *Abdomen* and is due to the relatively inert lead surface, compared to copper.

Figure 4.16: .38 calibre LRN Colour Results for Pig 1 and Human 1

4.5.3 Summary

The 9mm Parabellum calibre FMJ bullet samples recovered from the Pig and Human donor in the cool Australian conditions were examined by area of recovery, being the lungs, abdomen, and leg

muscles. The bullets from both Pig and Human were examined by qualified Forensic Firearms Examiners using the AFTE Range of Conclusions. The median microscopic scores for the pig indicated slightly irregular scores for the *Abdomen*, when compared to the *Lung* and *Muscle* median scores. This may be due to the complex microbial and/or chemical nature of the abdominal cavity. However, when compared to the microscopic results from the Human donor in cool conditions, all bullets could be identified to the control bullet, regardless of the area or time of recovery. From this, the microscopic examination of 9mm Parabellum copper jacketed FMJ bullets recovered in cool conditions should be able to be identified back to a known source, even after a period of 21-days exposed to a decomposition environment. The use of microscopic examinations and noting possible changes in microscopic striae could be of some value to investigations, by the provision of another scale to use in conjunction with current time-of-death interval estimates. The major limitations with this include the need for further studies in an Australian context, the variations in decomposition rates between cadavers and seasonal factors.

The development of the subjective corrosion scale was undertaken to assess the effects of decomposition from the test regions, being the lungs, abdomen, and leg muscles and to attempt to determine the length of exposure to a decomposing body. The copper jacketed 9mm Parabellum calibre bullets underwent varying degrees of corrosion on their surfaces, including the formation of black scale and red or blue discolouration. The *Lungs* and *Abdomen* displayed variations in the corrosion scores, whilst there was a relatively steady increase in corrosion for *Muscle.* For Pig 1, when the percentage of microscopic identifications is analysed against the corrosion scores, it was observed that as the corrosion scores increased, the microscopic identifications reduced (more inconclusive results made). Compared to the results for Pig 1, the Human results for this period showed that the bullets recovered from the *Abdomen* appeared to increase in corrosion, at day 9, whilst the bullets recovered from the *Lungs* did not corrode appreciably until day 15. Unlike the Pig 1 results, all copper jacketed bullets could be identified to a common source.

A second scale was developed to produce a readily available system, whereby examiners in the field (including post-mortems) could assist with a time of death estimate for bullets recovered from a decomposing gunshot victim. In conjunction with the observed corrosion, changes in colour were noticed, including discolouration of the copper surface to a dull gold and black colours. The 9mm copper jacketed bullets recovered from the Human *Lung* did experience a relatively steady increase in colour scores as exposure time increased, however, they did not display the variations in colour scores as seen with the Pig *Lung* sample copper jacketed bullets.

In the cool Australian conditions experienced during the timeframe of this project, the copper jacketed bullets did display some microscopic changes that may assist in time of death estimates, however for the most part, these bullets could be identified back to a common source. The use of the Corrosion and Colour scales to conduct any examination of coper jacketed bullets would need to be approached with caution, as the variations observed, especially for the *Lungs* and *Abdomen,* would mean that no significant information pertaining to time of death estimate could be relied upon.

Whilst no correlation was immediately obvious between the manual, microscopic examination results and the automated IBIS results, the ability of the IBIS system to image and then correlate the fired bullets was possible, with all bullets except one, being above the Unified Score threshold. The majority of bullets retrieved from *Muscle* fell within a lower Unified Score threshold band, which may indicate issues with the ability of the optical systems to acquire these bullets, which affected their threshold values. This is despite the microscopic results for *Muscle* all indicating median microscopic scores of +2 (Identification). The results from this study of pig decomposition in cool conditions, should provide some confidence in IBIS to readily correlate bullets from a decomposed environment.

Chapter 5: Bullet damage in Warm Climates

5.1 Meteorological Data

Additional samples were created and exposed to Australian summer conditions particularly for copper bullets, as decomposition is generally faster in summer (Vass, *et al,* 2002). There was a need to assess if more damage occurred to the test bullets over time in these warmer conditions, since the changes observed were not major in the cooler Australian conditions. The Hawkesbury region generally has warm summers. Data supplied by the Bureau of Meteorology (BoM) from the University of Western Sydney Richmond Campus shows an average summer (December to February) temperature range from 16 °C to 29 °C, with January being the warmest month. Rainfall in summer averages 89mm per month. The meteorological data was sourced using the Bureau of Meteorology (BoM) website which recorded data from the weather station at the Royal Australian Air Force (RAAF) Base, Richmond, New South Wales (BoM, 2022). The data shows the mean minimum and maximum temperatures (^{O}C), and the two relative humidity recordings (%) taken twice a day at 0900hour and 1500hour during the respective study periods. The data during the study periods are detailed in Table 5.1.

Table 5.1: Meteorological data – Warm Conditions. Royal Australian Air Force (RAAF) Base Richmond, New South Wales (BoM, 2022)

Table 4: Meteorological data					
Study	**Months**	**Mean minimum Temp (^{O}C)**	**Mean maximum Temp (^{O}C)**	**Mean relative humidity (%) (0900hr)**	**Mean relative humidity (%) (1500hr)**
Pig 2 & 3	October/ November	14.1	27.2	77.7	46.5
Human Donor 2	February	17.3	27.7	87	62

5.2 Visual decomposition

The visual decomposition of the two pigs in late spring and the human donor in summer (Figure 5.1) indicated a faster rate of decomposition than was observed for the pig and human donor in autumn and winter respectively (Figure 4.1). During the first sample day, the Pigs 2 and 3 appeared to be decomposing more rapidly than was observed with Pig 1 (Appendix 2.3), where bloating had ceased and the skin appeared to be dried, with some bones being exposed. By the completion of this phase, the pigs had progressed to the skeletonisation stage, where the majority of the bones were exposed, with some tissue and skin present (Figure A2.3(e), Appendix 2.3). One pig appeared to have a partial 'blanket' of skin covering the underlying bones, with little tissue remaining. The pigs both suffered some predation at this stage by an unknown animal, as sections

of skin were located approximately 10 – 15 metres from the test site and there appeared to be some digging or other disturbance around the cages. By the conclusion the only significant remains were bones, with some evidence of skin and hair within the cage. These two pig carcasses had undergone a faster rate of decomposition compared to the pig in autumn (Figure 4.1).

The decomposition of the human donor was slightly slower than that of the pigs. As noted on the initial sampling day there appeared to be less insect activity and the donor appeared to be in the early decomposition stage (Galloway, 1997). On day nine, decomposition had advanced, and the skin discolouration was observed over the entire body (Appendix 2.4, Figure 2.4(a)). On day 12, the decomposition proceeded to skin slippage and apparent loss of the eyes; insect activity had become extremely noticeable with maggots around the incisions and face (Appendix 2.4, Figure 2.4b). By the last sample day, the entire abdomen had collapsed, and the skin had turned a waxy-grey colour, with further decomposition to the face, neck, and groin regions, with the appearance of portions of limb bones (e.g., humerus, ulna, femur, and fibula). The collapse of the abdomen has been described in a study by Iqbal, *et al*, 2018, which states that this disruption of the abdomen occurs between ten to twenty days after death. This observation by Iqbal *et al,* 2018 is consistent with the observations in this study.

The period of this phase was characterised by persistent, heavy rain over most of this time and the average recorded rainfall for the period the of this portion of the study was approximately 358mm (BoM, 2022). As such, a white, fatty liquid had formed around the entire cadaver in a large pool, which had begun to run off away from the caged area.

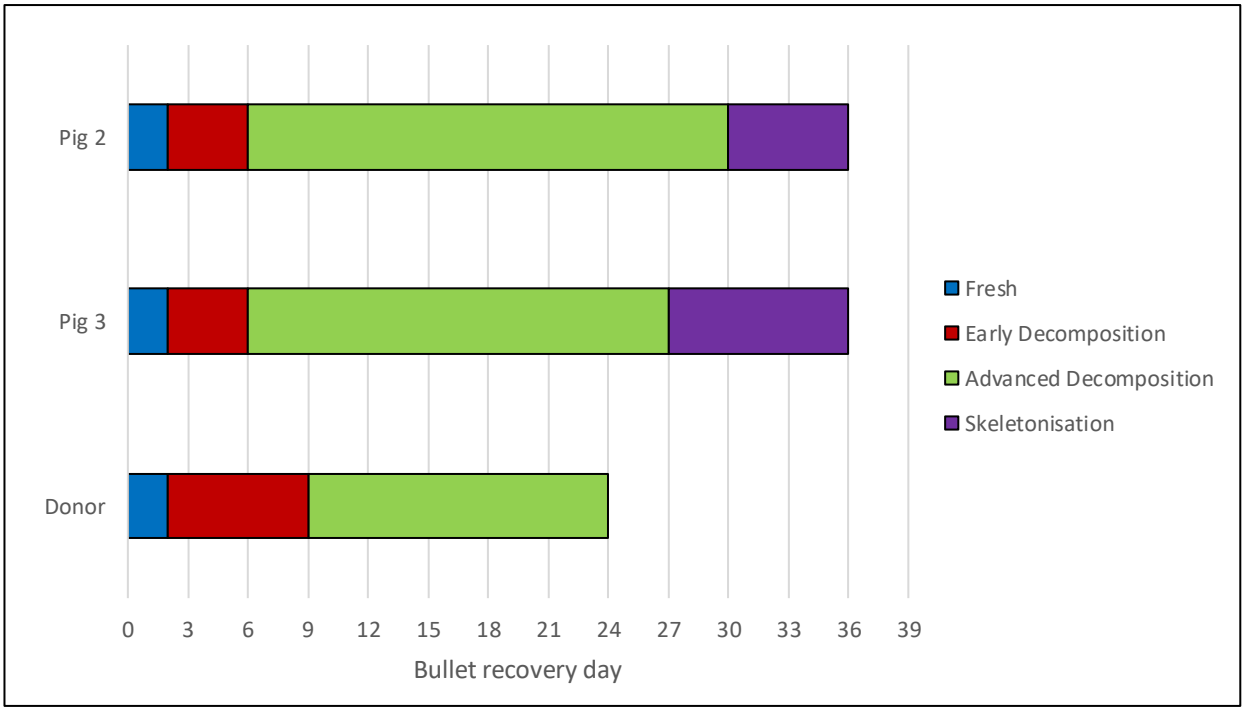


Figure 5.1: Observed decomposition stages – Warm Climate Trial

5.3 9mm Parabellum calibre copper FMJ bullets

5.3.1 Microscopy Results

The test fired bullets for this stage were discharged in a 9mm Parabellum calibre Norinco model NP22, with conventional rifling. The bullet samples recovered from the two decomposing pig carcasses in late spring were examined by the area of recovery, (lungs, the abdomen, and the muscles). The copper jacketed 9mm Parabellum calibre fired bullet samples were examined and displayed severe corrosion and were not suitable for any microscopic examination (Figures 5.2). This was due to the rapid decomposition rates of the pig carcasses that led to the rapid creation of more complex environments in all areas of the carcasses (Figures 5.3(a) to 5.3(c) and Figures 5.4(a) and 5.4(b)).

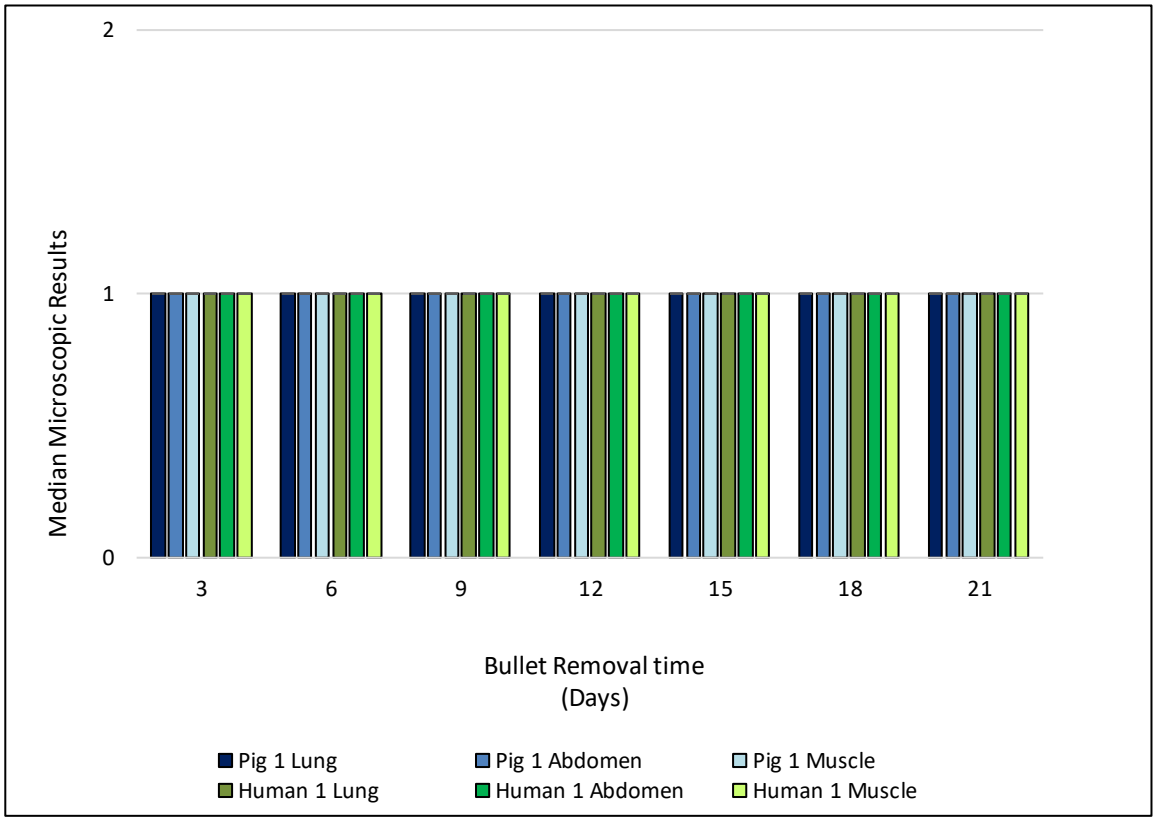


Figure 5.2: 9mm Parabellum calibre copper FMJ Microscopic Results for Pig 2/3 and Human 2, Error bar represents n = 5 examiners

The severe corrosion observed in the copper bullets has previously been discussed by Rao *et al* (2015), in which the author's state that there is a clear correlation between corrosion caused by decomposition processes and the obscuration of bullet striae.

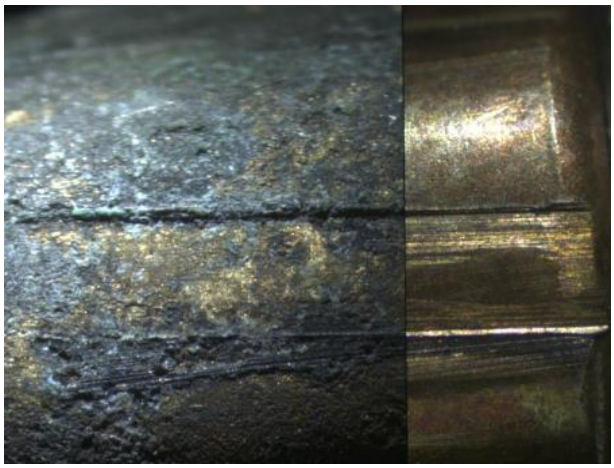


Figure 5.3(a)

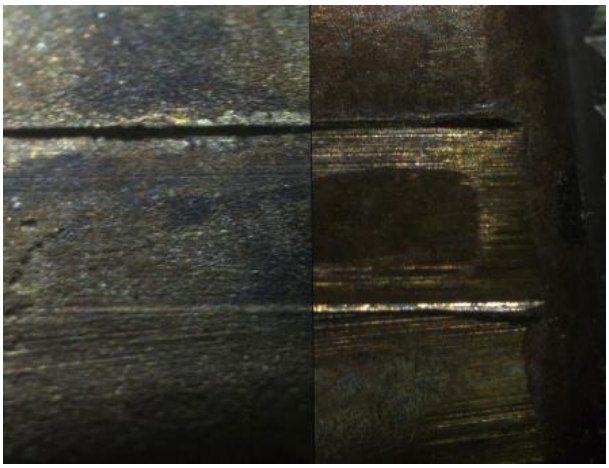


Figure 5.3(b)

Figure 5.3(c)

Figure 5.3: 9mm calibre copper jacketed bullet removed from (a) the pig carcass lungs at 9 days (b) the pig carcass leg muscle at 9 days and (c) the pig carcass abdomen at 9 days.

The bullet samples recovered from the second human donor in late summer were examined by the area of recovery, (abdomen, and the muscles) (Figures 5.4a and 5.4b). The copper jacketed 9mm Parabellum calibre fired bullet samples were examined and displayed severe corrosion and like the results for pigs 2 and 3 were not suitable for any microscopic examination (as previously displayed in Figures 5.3a and 5.3c). As described above with the pig carcasses, the severe corrosion was due to the rapid decomposition rates of the donor and increased microbial and chemical activity compared. The increased decomposition rates led to the rapid development of more complex environment in all areas of the second human donor.

Figure 5.4(a)

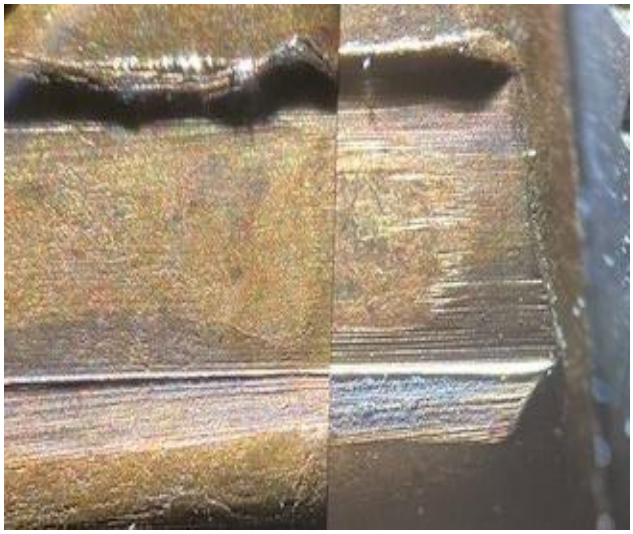


Figure 5.4(b)

Figure 5.4: 9mm calibre copper jacketed bullet removed from (a) the pig carcass lungs at 9 days (b) the pig carcass leg muscle at 9 days and (c) the pig carcass abdomen at 9 days.

5.3.2 Corrosion Scale Results

With the use of two pigs, three bullets were collected on each recovery day per area, being the lungs, abdomen, and leg muscle. One or two bullets were recovered per area, alternated between the two pig carcasses, for the test period, meaning that the corrosion (and colour) scores were averaged into single results for analysis (Figures 5.5 and 5.6). The first four sets of bullets were removed from the pigs, and it was noted that the level of corrosion was high as it was for all other recovered bullets. However, corrosion results for the bullets removed showed no variance for the pig *Lungs* and some variance with *Abdomen* and *Muscle* respectively. The *Abdomen* results indicated a relatively steady increase in corrosion scores as the test period increase, whilst the *Muscle* results were also steady, except for the second recovery time, with a decrease in the score (i.e., less corrosion noted).

The results for all areas of the human donor indicated an improvement in the corrosion scores with increased recovery days (Figure 5.5). The initial results for days three and six for all areas were medium to high, indicating that in some instances, the bullets had undergone relatively rapid corrosion, expected in warmer conditions, as seen with Pigs 2 and 3 in Figure 5.5. However, the overall results generally remained stable as the time increased. The *Lung* and Muscle corrosion results remained steady, with the *Abdomen* displaying some decrease in colour scores. This steady results for Lung and Muscle however did not translate to microscopic identification, all of which were inconclusive.

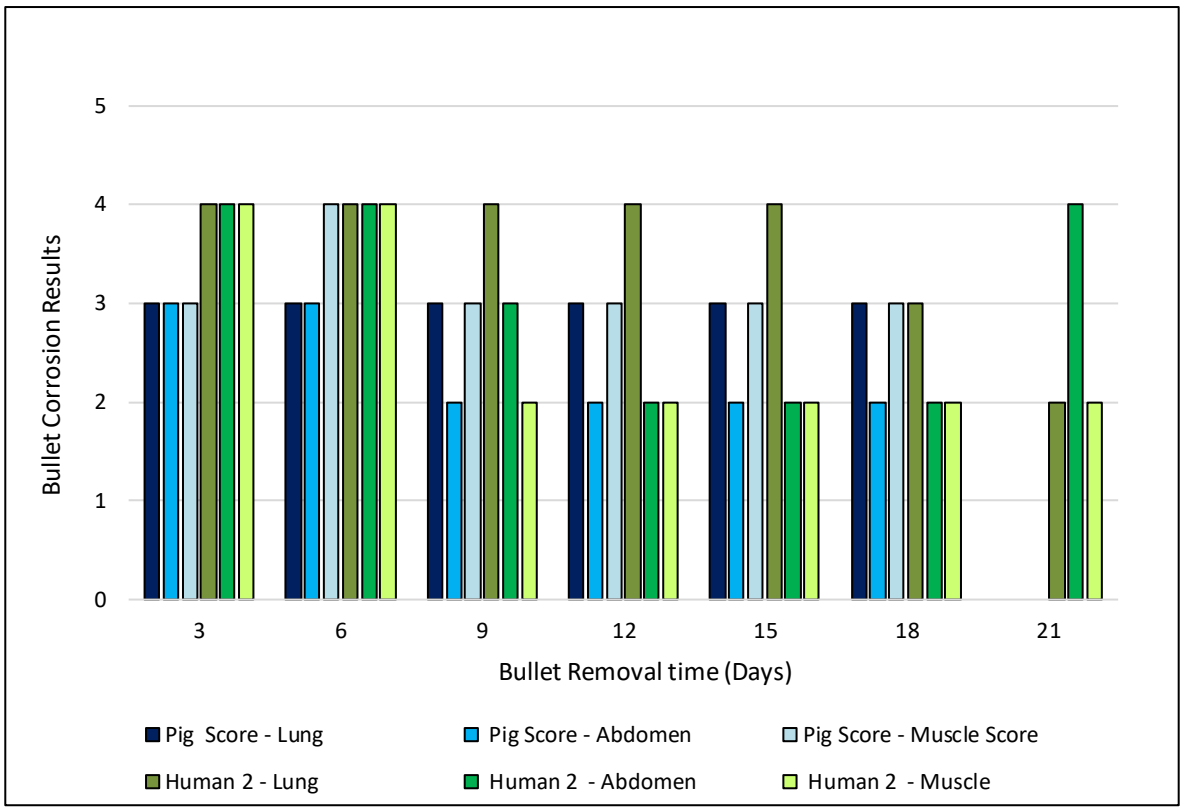


Figure 5.5: 9mm Parabellum calibre copper FMJ Corrosion Results for Pig 2/Pig3 and Human 2

The *Abdomen* results displayed decreased scores after day 6. As stated, there was substantial rainfall during this test period, and the abdomen of the cadaver had collapsed by the last day and many of the bones were exposed; the collapse of the abdomen and exposure of the bones at this period is consistent with the findings by Iqbal, *et al,* 2018). The steady scores recorded, despite the visual decomposition (section 5.2), may have been due to the ingress of rainwater, altering the chemical environment. The corrosion of bullets in water was addressed by Larrison (2006) where copper jacketed bullets were found to have corroded at a higher rate than those in the open-air environment and forest soil (Larrison, 2006).

The collapsed abdomen and exposure if the leg bones, thereby affecting the muscle, meant that some of the bullets placed in the *Abdomen* and *Muscle* may have been exposed to a combination of the decomposing and ambient weather conditions. This may also explain the levels of corrosion experienced by the bullets in the *Lungs*, that may have been exposed to the decomposition environment for a longer time, as the ribs and remained in place and 'protected' these bullets. The corrosion results then improved, as the lungs were eventually exposed to the heavy rain, altering the environment. Carter and Tibbet (2008) describe that extremely wet environments, which may have been experienced during this human trial, produces inhibited decomposition due to waterlogging of the specimen and adipocere formation.

5.3.3 Colour Scale Results

As previously stated with the corrosion results, the first four sets of bullets from the pig were removed, and each had experienced a high level of corrosion, as it was for all other recovered bullets. However, colour scale results (Figure 5.6) for the bullets removed indicated no variance with the *Lungs*, *Muscle* and *Abdomen* median scores respectively. Compared to the corrosion score, the bullets recovered displayed steady scores.

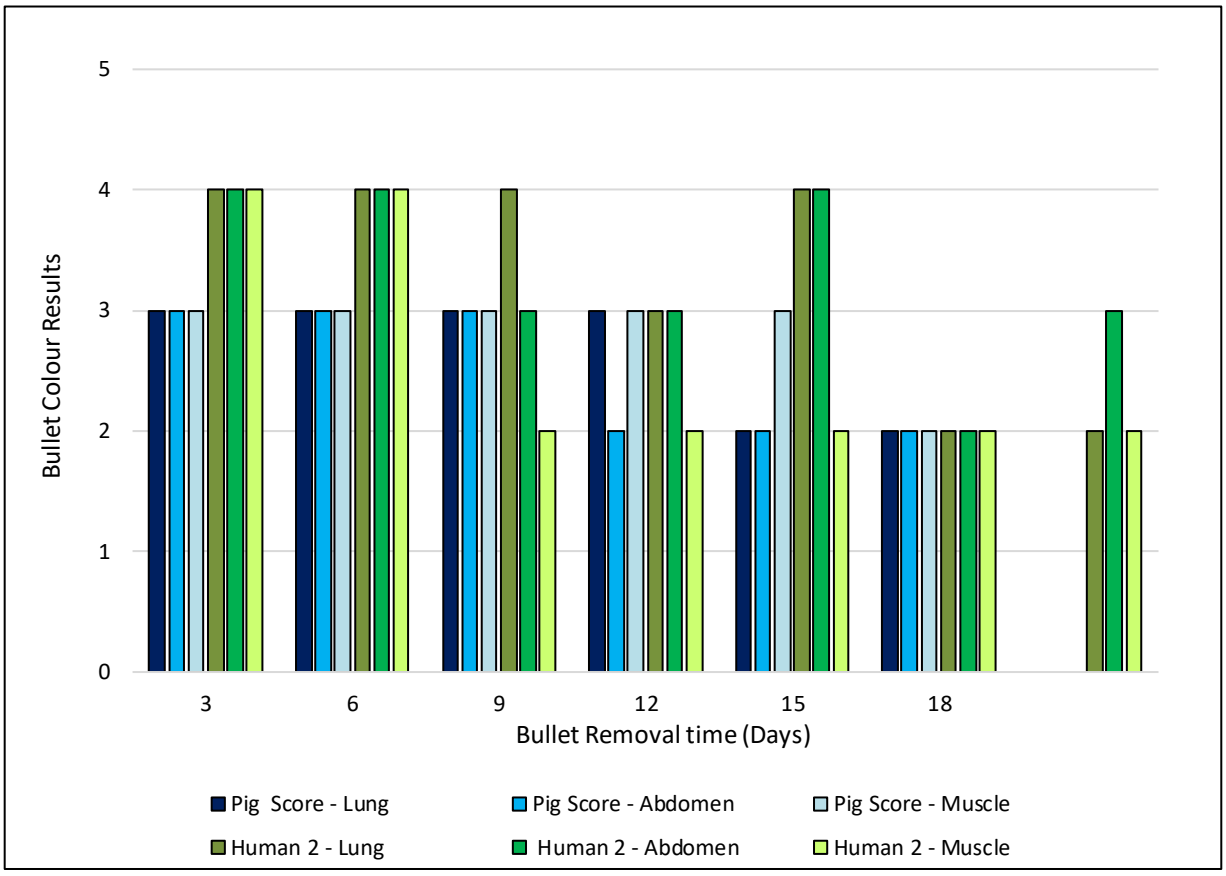


Figure 5.6: 9mm Parabellum calibre copper FMJ Colour Results for Pig 2/Pig3 and Human 2

The human donor results for the colour could be linked closely to the corrosion results, due to the excessive rain experienced and the decomposition of the cadaver (Figure 4.6). The assessed colour results improved (more akin to the control bullet) due to these bullets not being exposed to the decomposition environment and being exposed to the ambient weather conditions.

5.4 Integrated Ballistic Identification System (IBIS) Results

The IBIS results for the pig in warm conditions can be associated with the inconclusive microscopic results, as many of the correlation results below the designated threshold of 0.8 used on the MatchPoint+^{TM} system, with the results for *Lung* (blue), *Abdomen* (yellow) and *Muscle* (green) depicted in Figures 5.7 and 5.8.

Table 5.2: Fired bullet sampling days and bullet engraving for Pig 2 and 3 – warm conditions.

Set	Sample day	Bullet type	Engraved label	Comments
1	Day 3	9mm	WL1, WL2, WL3 WA1, WA2, WA3 WM1, WM2, WM3	The bullet type (9mm) in each set were all engraved with the following first letter, which denotes a colour (White, Green, Blue, Yellow, Red and Orange,) to distinguish these bullets from those from the study in cool conditions (see table 4.2). The second letter denotes the sample region: L = bullet from area targeting lungs. A = bullet from area targeting abdomen. M = bullet from area targeting leg muscle. The third character the bullet number, however the examiner did not know from which pig either bullets 1, 2 or 3 came from.
2	Day 6	9mm	GL1, GL2, GL3 GA1, GA2, GA3 GM1, GM2, GM3	
3	Day 9	9mm	BL1, BL2, BL3 BA1, BA2, BA3 BM1, BM2, BM3	
4	Day 12	9mm	YL1, YL2, YL3 YA1, YA2, YA3 YM1, YM2, YM3	
5	Day 15	9mm	RL1, RL2, RL3 RA1, RA2, RA3 RM1, RM2, RM3	
6	Day 18	9mm	OL1, OL2, OL3 OA1, OA2, OA3 OM1, OM2, OM3	

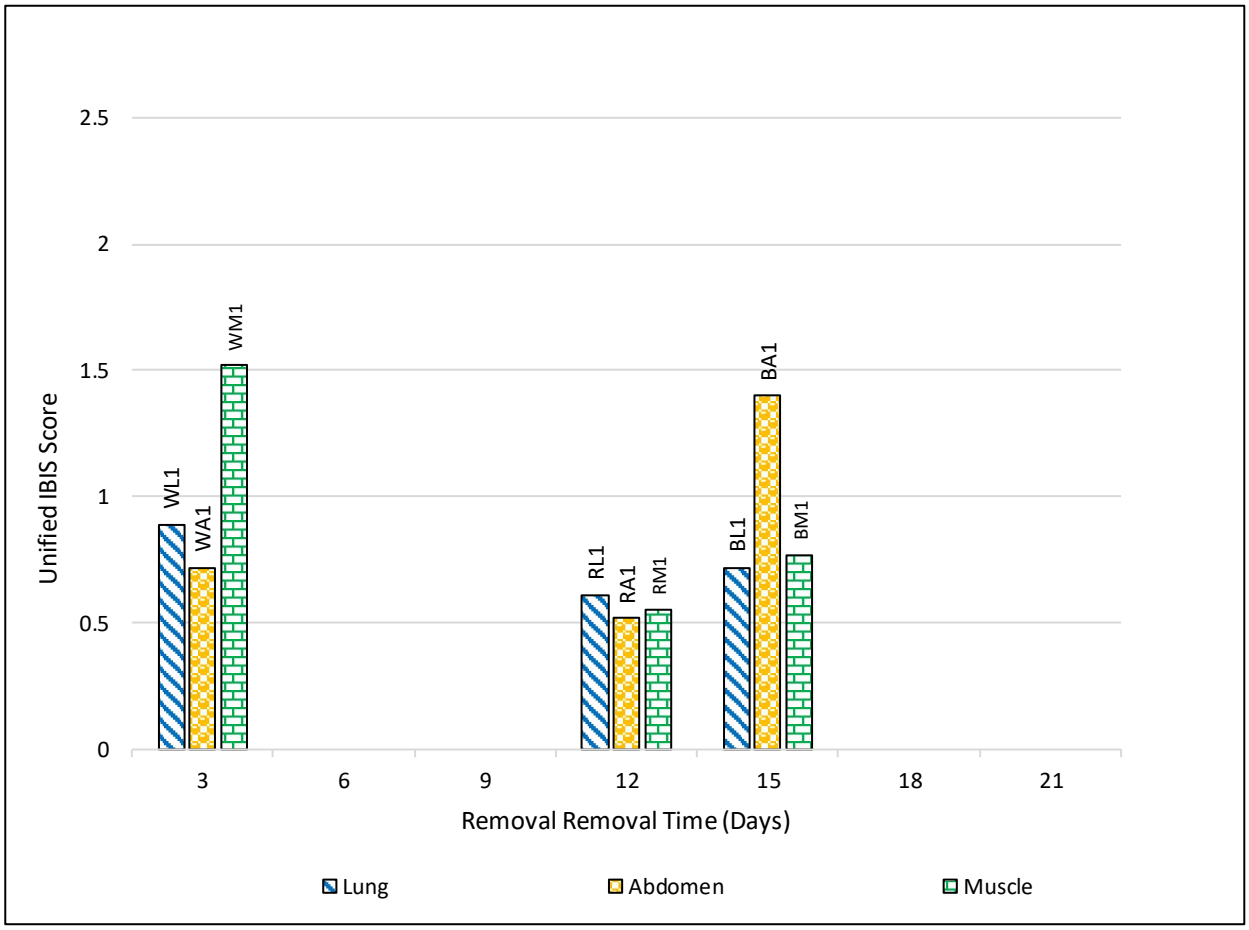


Figure 5.7: 9mm Parabellum calibre copper FMJ Colour Results for Pig 2/Pig 3

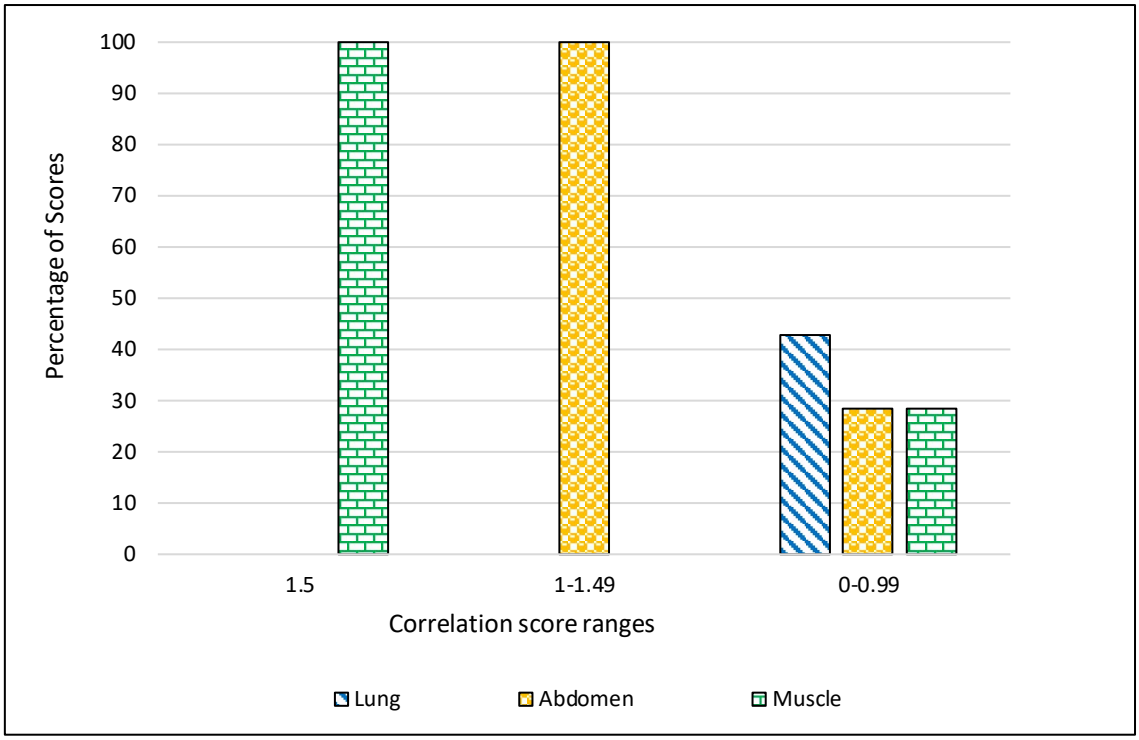


Figure 5.8: Percentage of correlation scores for retrieval areas for 9mm calibre copper bullets from Pig 2/Pig3

Figure 5.9: Screenshot of an acquired bullet 9mm calibre copper bullet (RM1) from Pig 2/Pig3

These results highlighted the difficulty in acquiring images on to the IBIS system due to the greater surface corrosion (Figure 5.9), with increased decomposition rates, and relatively low scores. Compared to the IBIS results in cool conditions, where only one image scored below the threshold

score, in warm conditions, only three bullets scored above the threshold score, which accounted for one-third of those bullets acquired.

5.5 .38 Special and .45 Colt calibre lead bullets

5.5.1 Microscopy Results

The test fired bullets were all discharged in a .45 Colt calibre Winchester model 1892 rifle, with conventional rifling. A total of five qualified forensic firearm experts participated in the analysis of .38 calibre lead fired bullet samples recovered from the pig and human. The results indicated a unanimous inconclusive result for all lead .38 Special recovered samples from both pigs and human trials across the entirety of the recovery period and from each recovery location being the *Lungs, Abdomen* and *Muscle*. A total of four qualified forensic firearm experts participated in the analysis of the .45 Colt calibre fired bullets (Figure 5.7) recovered from the human donor. The .45 Colt calibre bullets recovered from the specimens provided more information for the examiners in terms of microscopic striae than from the .38 Special calibre fired bullets recovered. It can be noted that there are variations in *Lung* and *Abdomen* scores for the duration of the exposure period, whilst there is a steady decrease in the median microscopy scores for *Muscle* (albeit with the last bullet from *Muscle* not being recovered). These results for lead bullets in the Human *Abdomen* follow a similar pattern to the copper bullets exposed to the *Abdomen* in Pig 1, which were slightly irregular and did not follow a steady trend in microscopic examination scores as exposure time increases.

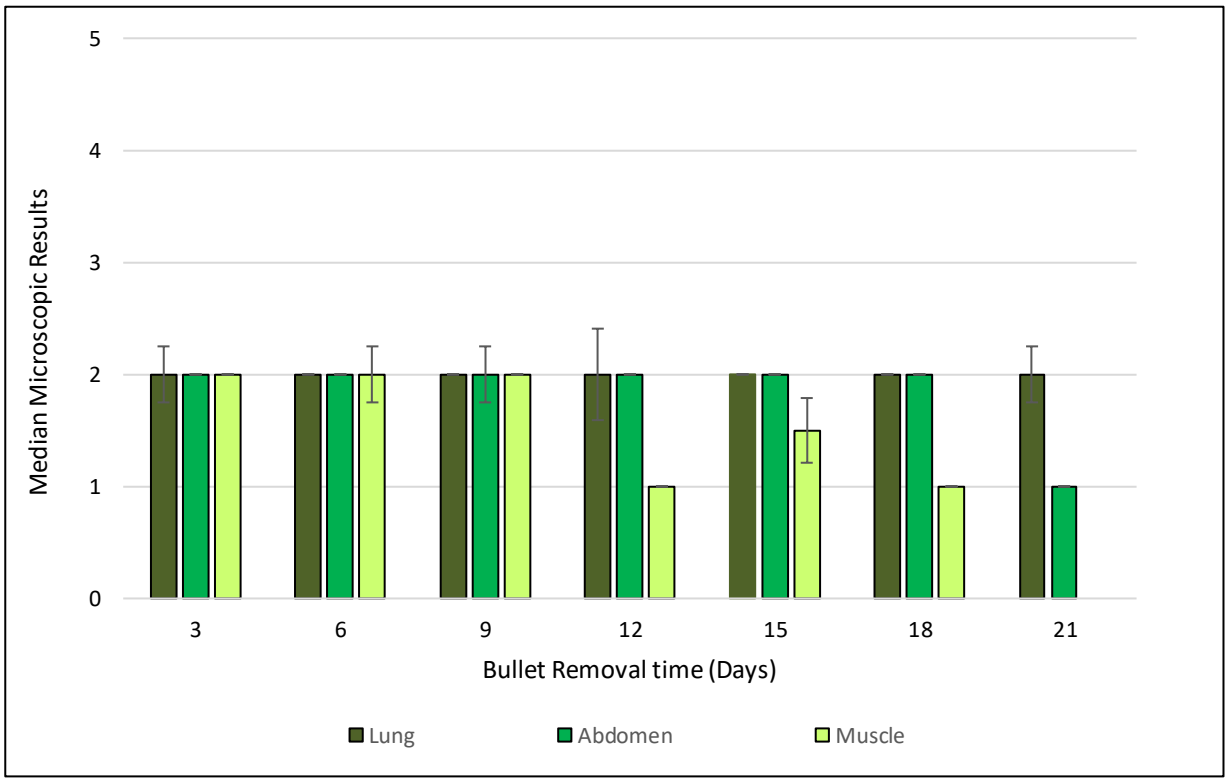


Figure 5.10: .45 Colt calibre LRN bullets Microscopy Results for Human 2. Error bars represents n = 4.

Love (1980) reported that lead bullets exposed to decayed blood (blood exposed to the environment) for nine months displayed more corrosion than the bullet retrieved from the decayed blood after one month, however exposed lead bullets were still identified to the control lead bullet (Love, 1980). Whilst decomposed blood alone does contain the number of other chemical by-products associated the decomposition of an entire cadaver, the result by Love (1980) and the number of identifications made of lead bullets in this study (Figure 4.7), would indicate that lead is a relatively inert metal and not overly affected by decomposition processes.

5.5.2 Corrosion Results

Visually it was noted that the recovered lead .38 Special fired bullet samples from Pigs 2 and 3 had a slight amount of corrosion on the surface and appeared to be visually like those bullets recovered from the Pig 1 and Human 1 tests in cool conditions (Figure 4.9). Smith *et al*, 1993, reported that at the end of the exposure period of 66 days, the major changes occurred to those lead bullets exposed to muscle and 'lateral' adipose tissue, with no or little observed change in the bullets exposed to the head, abdomen, or chest. This research exposed the lead bullets to the chest, abdomen, and muscle for a period of 36 days and no major changes were noted on the surface of these lead bullets in this timeframe.

Visually it was noted that the recovered lead .45 Colt calibre fired bullet samples from Human 2 (Figure 5.8) did display some brown/white discolouration (tarnish) and some white coloured, solid products adhering to the surface, which did hinder identification, but did not produce the major changes observed on the copper bullets for Pigs 2 and 3 and Human 2 in warm climates. This indicates that lead bullets are relatively inert regarding reactions with the chemical by-products present during the decomposition process in the timeframe (21 days) tested during this research.

Figure 5.11: Combined .45 Colt calibre LRN bullets recovered from the Muscle of Human 2, with increasing exposure time (left to right).

5.5.3 Colour Scale Results

The colour results for the .38 calibre LRN pig bullets were again subtle and generally confined to a white/yellow or yellow/brown discolouration on the lead bullet's surface. No scaling or other corrosion (oxides) previously reported by Smith *et al*, 1993 was observed on these lead bullets.

The results for the .45 Colt calibre bullets colour score (Figure 5.9) can be seen to approximately follow the colour results for the 9mm Parabellum calibre copper bullets (Figure 5.5) in that the results for *Abdomen* improved at various points with time (higher scores), which could be due to the excessive rain experienced and the decomposition of the cadaver. The assessed colour results for the .45 Colt calibre lead bullets recovered from the *Abdomen* were variable, and in some instances improved (more akin to the Control bullet), which is likely due to these bullets being exposed to the decomposition and ambient environment. The bullets recovered from *Muscle* were assessed to have high colour scores (no appreciable colour changes for the first four sampling days, however, day 9 did show a drop in the assessed colour score, before increasing again and stabilising for the remainder of the sample period (days 12 to 21). This single result is relatively unusual for *Muscle,* given the relatively stable results for bullets recovered from muscle tissue throughout the study. This could again be attributed to the inclement weather, which affected the decomposition environment. However, it is generally noted that the surface of the .38 and .45 calibre bullets is relative inert nature (lead) in the decomposition environments. The lungs may have been protected from the elements during this period and therefore may demonstrate the relative stability of lead.

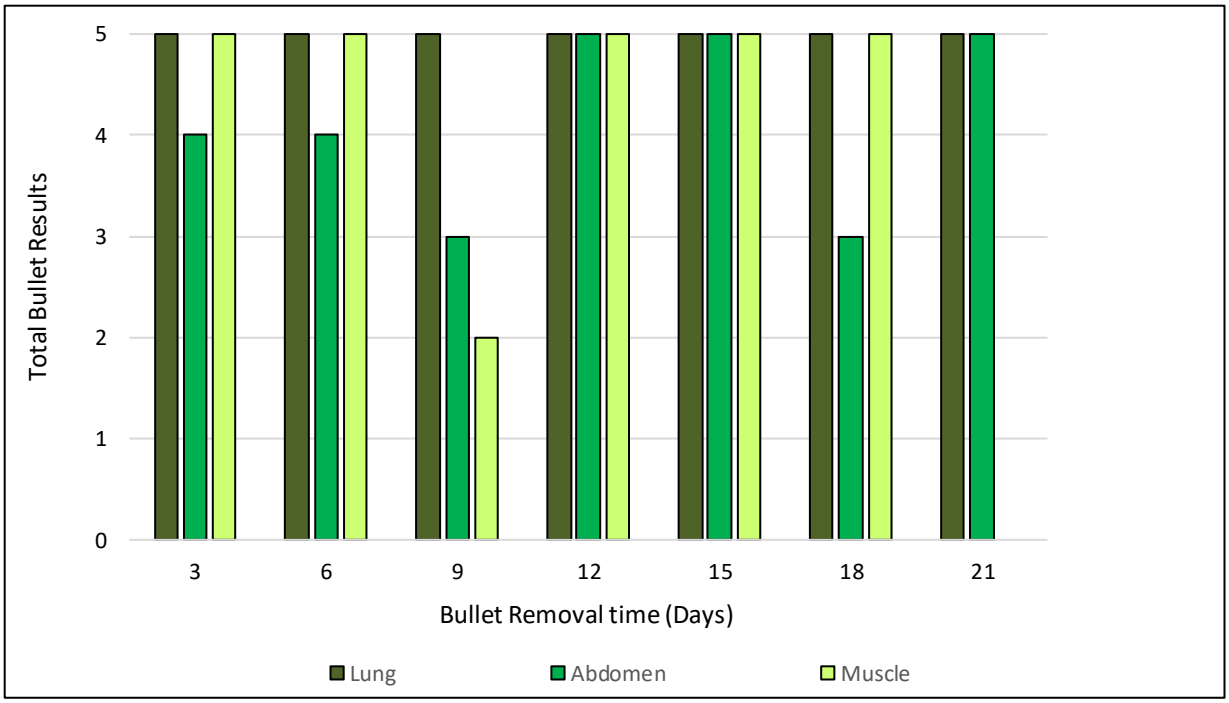


Figure 5.12: 45 Colt calibre LRN bullets Colour Results for Human 2

5.6 Summary

The 9mm Parabellum calibre FMJ bullet samples recovered from the two Pig carcasses and Human donor in warm Australian conditions were examined by area of recovery, being the lungs, abdomen, and leg muscles. The bullets from both Pig and Human were examined by qualified Forensic Firearms Examiners using the AFTE Range of Conclusions and all bullets were found to be heavily corroded even after the first recovery periods of six days (for pigs) and three days for the human donor. The pig results were all inconclusive due to the excessive corrosion, whilst some variations in microscopic classifications did occur with the Human 2, where some positive and inconclusive results were returned for Lungs (bullet retrieval days three and fifteen), Muscle (bullet retrieval days six and fifteen), and Muscle (bullet retrieval days three, six and nine). However, no agreement on identifications were recorded by all examiners for any bullets retrieved. These results can primarily be due to the rapid decomposition of both pigs and human specimens in warmer conditions, where higher temperatures and humidity were experienced.

The corrosion results for the 9mm copper jacketed bullets removed from the Pigs did show some variance with the Lungs and less variance with Muscle and Abdomen respectively. The Abdomen results indicated a relatively steady decrease in corrosion scores as the test period increase, whilst the Muscle results were also steady, except for the second recovery time (Day 12), with an increase in the score (i.e., less corrosion noted). The corrosion results for the copper bullets recovered from the Human donor did initially show a level of corrosion expected given the warm conditions. These results generally steadied or improved as the Human decomposition time increased, which is possibly due to the amount of rain received during this test period and the effect on the chemical and microbial environment.

The 9mm copper jacketed bullets recovered from the Pigs also displayed observed variance with the colour scores in the Lungs and less variance with the Muscle and Abdomen. However, as with the corrosion scores, there was a steady increase in colour scores for Muscle. It can be observed that the results from Muscle were relatively steady for both corrosion and colour scales, compared to those from Lungs and Abdomen

The .38 calibre lead bullets from the two pig specimens were microscopically analysed by qualified forensic firearms examiners. Each lead bullet was inconclusive and therefore no meaningful data could be deduced. When employing the corrosion scale for the .38 calibre bullets recovered from the pigs, there was a slight amount corrosion observed after the thirty-six-day exposure period. There were only slight changes in the lead colour scale, with the colour confined to yellow and yellow/brown areas on the surface.

The .38 Special LRN calibre bullet samples recovered from the Pig and Human donor in the cool Australian conditions were examined by area of recovery, being the lungs, abdomen, and leg muscles. The bullets were all microscopically determined to be inconclusive in accordance with the AFTE Range of Conclusions. The lead bullets did display some corrosion, which were observed to be a 'yellowing' of the surface. The results for the observed colour on the lead bullets demonstrated an increase in colour scores for Abdomen and Muscle, unlike those for Lung, which indicated one variable result. This differs from the colour results for the 9mm Parabellum calibre copper jacketed bullets from Pig. This can also be due to the relatively inert lead surface, compared to copper. The colour scale results for the .38 Special LRN bullets recovered from the Human did not show any discolouration, with the exception for one lead bullet displaying a yellow/brown colour for the Abdomen at day 9. In the cool Australian conditions experienced during the timeframe of this project, the lead bullets did not display any significant changes that would assist in time of death estimates.

The microscopy results for the Human donor with the .45 calibre lead bullets, with microscopic identifications made by the forensic examiners. As with other results, there were more variations in results for *Lungs* and *Abdomen* and a steady decrease in microscopic identifications for *Muscle* results. The corrosion results for the .45 lead bullets did display some changes, with some white products adhering to the lead surface that hindered identification. However, these corrosion results did not produce the major changes on the surface of the lead bullets when compared to the surface of the copper jacketed bullets. The colour results for the .45 calibre bullets in the Human donor were relatively stable and, in some instances, improved as the exposure time increased. This could be due to the relatively unreactive nature of lead in the decomposition environment and the excessive rainfall experienced during this time.

The manual microscopy and automated IBIS results did highlight the difficulty in identifying any useful information on the surface of the bullets exposed to the pigs in warm environments. The surface corrosion experienced by these bullets was sufficient to render only one-third of the acquired bullets above the unified score threshold, with the remaining bullets acquired all receiving relatively low scores. This contrasted with the scores from cool conditions, where only one bullet scored below the threshold score.

The main issue for examiners in the field is that copper jacketed bullets recovered from a decomposing cadaver in warm conditions will likely be corroded such that any useful microscopic information (striae) will have been potentially lost. Besides the requirement to remove bullets from decomposed bodies in a timely fashion, other cleaning techniques, beyond the scope of this project,

could be investigated as a potential avenue to remove scale attached to the copper jacketed bullet's surface, thereby allowing the striae to potentially be observed. However, if the corrosion has attacked the surface, where new chemical species have been formed from the reaction of the copper with decomposition products, then no amount of cleaning could save the microscopic striae for further examination.

Chapter 6: Conclusions and Future Work

6.1 Conclusions

The pilot study was undertaken to determine a suitable method of retrieving the bullets exposed to the decomposition environment, to ensure the bullets could be retrieved from specific locations, whilst minimising exposure to the biological fluids. This phase successfully informed part of the future filed studies, in that the method developed to attached metallic eyelets and picture framing wire to the bullet was successfully undertaken in cows' blood in laboratory conditions. Whilst no data was collected per se, the attachment method employed was successfully transferred to the field phase.

The field phase of this research project concentrated on the effect of pig and human decomposition processes on 9mm calibre copper jacketed, .38 and .45 calibre lead round nose bullets in cool and warm conditions. As anticipated, the decomposition rates for both pig and human bodies were reduced during the cooler conditions, including differences in decomposition rates due to biological differences between the species. The pig was visually assessed as reaching an advanced decomposition stage by day 21, whilst the human was assessed at reaching early decomposition by day 21. In warmer conditions, the decomposition rates were faster, with the pigs reaching skeletonisation at day 21 and the Human donor reaching this stage at day 18.

All bullets were exposed to either the pig or human and examined by the area of recovery, being the *Lungs, Abdomen* and (leg) *Muscle*. The examinations involved microscopic comparisons and assessment of surface corrosion and colour changes of all recovered bullets from the pig and human.

The combined microscopic analysis of the 9mm calibre copper jacketed FMJ bullets in the pig demonstrated a minor decrease in microscopic scores as the exposure time increased, indicating that the ability to identify an exposed bullet to the control was becoming slightly more difficult. This was a result of the damage to the copper bullet's surface and therefore the striae used in the comparison process. When the pig scores were adjusted to the respective median results, the pig abdomen demonstrated two instances where the scores differed, provided inconclusive results. These variations are postulated to be the result of the complex chemical and microbial environment present during *Lung* and especially *Abdomen*, decomposition.

The combined microscopic analysis of the 9mm calibre copper jacketed FMJ bullets in the human were also examined and found that all the recovered copper jacketed bullets could be

identified to a common source. This indicated that the decomposition of the human did not affect the fired bullet striae.

The 9mm copper jacketed FMJ bullets underwent corrosion of the surface, involving the dulling of the copper and the production of black scale. The variations in the pig lung and abdomen corrosion scores may again be due to the complex chemical and microbial environments, whereas the results for the pig muscle indicated a relatively uniform increase in corrosion over the study time. The combined identification and corrosion results for the pig indicated that as the corrosion becomes more pronounced (i.e., higher score) the percentage of microscopic identification scores are reducing, meaning that less identifications were made. Conversely, as the number of inconclusive results increase, the corrosion scores increase (more corrosion), which indicates that increased corrosion affects the microscopic striae and the examiner's ability to identify bullets to a known source.

All the recovered 9mm copper jacketed bullets from the human were identified to a common source, however, the bullets did undergo some corrosion during exposure to the decomposing human. The human corrosion results did indicate that the bullets recovered from the *Lung* and *Abdomen* increased as exposure time also increase, with the abdomen becoming corroded by day 9, whereas the lungs corroded at day 15. These corrosion results did not affect the microscopic examination of the fired bullets from the human, due to the slower decomposition.

As with the corrosion, the colour scores were established because of observing the different colours attributed to the recovered bullets. The colour scores for the pig were variable and did not show any distinct trend. The pig *Lung* and *Abdomen* results could be due the previously explained decomposition environments experienced. However, the *Muscle* scores were also variable compared to the previous microscopic and corrosion results. When analysis of the percentage of microscopic scores against colour scores was also relatively variable with identification and inconclusive scores, except for *Muscle*, which demonstrated a trend of decreasing identifications as the colour score increased. The colour scores for the human were steady for muscle and showed an increasing colour score as exposure time increased for bullets recovered from the *Lungs; Abdomen* scores were also variable as was seen with other results for microscopic and corrosion analysis. The results for the pig and human colour scores may be due to the actual development and assigned colour scores, which may need to be refined before further analysis using this scale should be undertaken.

The microscopic results for the .38 LRN fired bullets resulted in inconclusive results and little to no corrosion was visually determined for lead from either pigs or humans. The lead surface of the .38 calibre lead bullets recovered from the pigs did undergo some minor colour changes, primarily of a yellow-brown surface marking, however, no scaling, as seen on the 9mm copper bullets was observed. The lead colour scores for pig indicates a slightly increasing colour score as exposure time increased, although the lead bullets appeared to be unreactive to the decomposition processes. The slower decomposition of the human resulted in only one change noted visually in the colour analysis for the bullets recovered from the human. These results for lead carried over to the warmer conditions with the .45 calibre lead bullets, where corrosion and colour changes were minimal.

This research has highlighted that the reduced decomposition rates in cooler conditions has some effect on the ability to microscopically identify exposed copper jacketed bullets to a common source, although identifications may still possible up to twenty-one days after exposure to the decomposition environment. Conversely, the higher decomposition rates in warmer conditions results in greater effect to the surface of the copper jacketed bullets, hindering microscopic identifications as early as three days after insertion. The creation of the subjective corrosion and colour scales did not provide any definitive results to allow for time-of-death estimates using these scales, although as with the microscopy results, any corrosion or discolouration occurred rapidly in warm conditions and slowly in cooler conditions. Any copper jacketed bullets recovered from a deceased person with discolouration, black scale and/or dull gold coating would indicate exposure to the decomposition environment.

The .38 and .45 lead bullets proved to be relatively unreactive in the decomposition environments tested. There was little effect on the lead surface, which could hinder microscopic identification, with some by-products adhering to the surface, affecting identification. The corrosion and colour scales for lead did not provide any definitive results either, as the lead bullets remained relatively unaffected, with only some discolouration confined to yellowing or yellow/brown tarnishing observed.

This research also indicated that the *Muscles* in both pig and humans produced relatively steady results in terms of declining microscopic identifications and increased corrosion and discolouration results, especially for copper jacketed bullets. The results for Lungs and Abdomen produced more variations in the results, presumably due to the complex chemical and microbial environments in these tissue types and areas.

Finally, as with all subjective assessments, the human factor cannot be overlooked. Some examiners may naturally be cautious in their approach to microscopy and will likely give an inconclusive result compared to other examiners. This subjective assessment is largely based upon the examiner's training and experience. An inconclusive result may influence the results by one-point; however, this may be enough to create or hide a possible trend as seen above with the *Lung* scores slightly increasing over time, compared to the *Abdomen* and *Muscle* scores. Secondly, bias cannot be discounted either, as the examiners may have assumed that the fired bullets were from the same firearm and after a period, the examiners may have subconsciously made positive identifications as they became more familiar with the bullets.

6.2 Limitations

There were limitations identified during the practical phase of this research. One limitation is the number of bullets inserted into each carcass and cadaver, and the number of individual wounds in each. With the limited number of donors available, this will be an ongoing issue for any future work of this type. The project may not have replicated actual scenarios, in that the fired bullets were inserted and not fired into the pig carcasses and human donors. The primary reason for inserting the fired bullets was based upon the ethics issues of discharging a firearm into human donors. It was not possible to discharge bullets into the human cadaver; therefore, it was only appropriate to follow the same method and not fire bullets into the pig carcasses. Secondly, there are the legal and safety implications of discharging a firearm at the animal research facility, which is not a dedicated firing range, and has a residential property and public road adjacent to the site.

The rationale behind inserting fired bullets into the pig and human specimens was informed by the literature review, in that one of the previous research projects conducted involved bullets being fired into pig carcasses. This resulted in some bullets not being retained in the pig carcass, and there was no indication of whether the bullets had targeted specific organs. Past research had informed my method of targeting specific organs and removing the bullets at specified times.

There is also the issue of discharging a firearm into the pig carcasses that may add realism to the project, in that the fired bullet could strike bone and become damaged. If the bullet is damaged from striking bone, it could be possible that some variations in corrosion rates due to decomposition could occur. It could be that the rifling impressions on the bullet's surface has already compromised the integrity of the copper surface, but future work could involve the deliberate damaging of the bullet during firing (e.g., ricocheting the bullet from a non-yielding surface such as steel and capturing the bullet post impact), before insertion into the pig and/or human donor.

Whilst the pig carcasses and human donors were protected by wire cages within the field site, some predatory interference from the local wildlife was noted, however the presence of the metal cages would have deterred further interference, compared to an exposed body dumped due to criminal activity in a similar environment. Another limitation is the 'movement' of the carcass during decomposition, due to the bloating and rupturing, which may cause bullets to dislodge and therefore no longer be exposed to the specific tissue location being targeted. The final part of the practical phase involving the second human donor in warm weather conditions was conducted during a period of prolonged and intense rainfall. This would have resulted in a change to the chemical and microbial environment, which may alter the decomposition rates of the bullet types.

6.3 Future Work

Future work could be conducted to analyse the changes that occur to the copper and lead surfaces and specifically identify the by-products observed on each bullet type. Future research could be conducted into the surface changes observed, such as the change in copper present between the control bullets and when these bullets attain the dull gold surface colour. This analysis could be extended to understanding the differences noted in corrosion rates in cold conditions experienced in the Northern hemisphere including at the taphonomy research facility at the University of Quebec in Trois-Rivières, Canada (Contenta, 2019). Confirmation of the chemical makeup of the black scaling and discolouration on copper bullets and the yellowing observed on lead bullets could also be undertaken. The rate of formation of these chemical species may assist in time-of-death estimates. Future work in this field may also be conducted on bullets of different surface and jacket types, such as nickel, brass, and copper wash.

Additional work could be undertaken to remove any possible bias that may have occurred in this project, by firing bullets from different pistols of the same make and model. This would ensure that the microscopic examinations involved analysis of open sets of fired bullets. It is also anticipated that any future studies would continue to utilise the IBIS/MatchPoint+™ system, to ensure that there are minimal bias and a more objective manner of correlating bullet marks by way of using algorithms. Where possible, the use of Virtual Comparison Microscopy (VCM) should also be considered, which would allow for comparison examinations to be undertaken remote to the actual bullets and establishing an objective approach to comparison work between multiple examiners.

The aim of this research was to investigate the impact of decomposition on the degradation of fired bullet striations via corrosion mechanisms, which may be used to determine the degraded bullet's

potential for time-of-death estimation. The project achieved the aim of demonstrating that fired bullets may no longer be identifiable, after targeting specific tissue types and regions within decomposing human and pig analogues at general exposure times based on seasonal factors. The project demonstrated that in cool conditions, copper jacketed bullets can be identified up to at least 21 days following insertion into a human cadaver, whereas this time is reduced to less than three days in warm conditions. The project also demonstrated that lead fired bullets are relatively unaffected by the decomposition environment in either cool or warm conditions. These conclusions were achieved through microscopic examinations utilising qualified firearms examiners and computer-based correlations of the sample bullets and the development of a development of a corrosion scale. This research can assist future casework by informing investigators of the potential time a person was shot, due to the damage and corrosion present of any recovered copper jacketed fired bullets. It will also assist informing the best timeframe in which recovered bullets should yield suitable results depending upon the season.

References

1. Aoi, W. and Marunaka, Y. 2014. *Importance of pH Homeostasis in Metabolic Health and Diseases: Crucial Role of Membrane Proton Transport.* BioMed Research International, 2014: 598986. Viewed 22 March 2023. www.ncbinlm.nih.gov/pmc/articles/PMC4180894.
2. Association of Firearm and Toolmark Examiners (AFTE) 2020, *AFTE Theory of Identification as it Relates to Toolmarks*, viewed 15 June 2020. www.afte.org/about-us/what-is-afte/afte-theory-of-identification.
3. Association of Firearm and Toolmark Examiners (AFTE) 2020, *AFTE Range of Conclusions*, viewed 15 June 2020. www.afte.org/about-us/what-is-afte/afte-range-of-conclusions.
4. Australian Bureau of Statistics (ABS), 2006, *4397.0 - Firearms Deaths, Australia, 1980 to 1995*, viewed 3 July 2020, https://www.abs.gov.au/AUSSTATS/ABS.NSF
5. Australian Criminal Intelligence Commission (ACIC), 2021, Australian Ballistics Information Network (ABIN), Statistics Summary, retrieved 28 April 2021.
6. Australian Institute of Health and Welfare 2017. *Firearm injuries and deaths fact sheet*. Viewed 3 July 2020. Cat. No. INJCAT 187. Canberra: AIHW. ISBN 978-1-76054-098-2 (PDF). www.aihw.gov.au/getmedia/20368-firearm-injuries-deaths.pdf
7. Beech, I.B., Sunner, J.A, Arciola, C.R, and Cristiani, P. 2006. *Microbially-influenced corrosion: Damage to protheses, delight for bacteria.* The International Journal of Artificial Organs, vol 29, number 4, 2006.
8. Best, B.A. and Gardner, E. A. 2022, *An Assessment of the Foundational Validity of Firearms Identification Using Ten Consecutively Button-Rifled Barrels.* Association of Firearm and Toolmark Examiners Journal, volume 54, number.1, Spring 2022.
9. Benton, B. Watson, D. Ablah, E. Lightwine, K. Lusk, R. Okut, H. Bui, T. and Haan, J.M. *Demographics and Incident Location of Gunshot Wounds at a Single Level I Trauma Centre.* Kansas Journal of Medicine. 2021; 14: 31–37. Published online 12 February 2021.
10. Bridgemon, R.R. 1986. *Cartridge Case Ageing.* Association of Firearm and Toolmark Examiners Journal, volume 18, number.1, January 1986.
11. Moss Vale, New South Wales Climate Statistics, Bureau of Meteorology, Australian Commonwealth Government. http://www.bom.gov.au/climate/averages/tables/cw_068239.shtml
12. Richmond, New South Wales, Daily Weather Observations, Bureau of Meteorology, Australian Commonwealth Government, http://www.bom.gov.au/climate/dwo/202007/html/IDCJDW2119.202007.shtml.

13. Blau, S. Sterenberg, J. Weeden, P. Urzedo, F. Wright, R. Watson, C. 2018. *Exploring non-invasive approaches to assist in the detection of clandestine human burials: developing a way forward*, Forensic Science Research; 3(4): 304–326. Published online 7 February 2019 Feb 7. doi: 10.1080/20961790.2018.1493809.
14. Bricknell, S. 2020, *Homicide in Australia 2017-2018.* Statistical Report 23, Australian Institute of Criminology, viewed 3 July 2020. www.aic.gov.au/sites/default/files/2020-05/sr23_homicide_in_australia_2017-18.pdf
15. Brundage, J., *The Identification of Consecutively Rifled Gun Barrels*, Association of Firearm and Toolmark Examiners Journal, volume 30, number.1, Summer 1998.
16. Bryant, J. Chadwick S, Bolton, M.S. 2019, *Investigating the rates of corrosion to determine the age of fired cartridge cases in the field.* Honours Report, Centre for Forensic Science, University of Technology, Sydney.
17. Bureau of Meteorology 2020, Climate Statistics for Australian Locations, viewed 8 August 2020, http://www.bom.gov.au/climate/averages/tables/cw_067021_All.shtml.
18. Carter, D.O, Yellowlees, D and Tibbett, M. 2007, *Cadaver Decomposition in Terrestrial Ecosystems.* Naturwissenschaften (The Science of nature), volume 94, p. 12 – 24. https://doi.org/10.1007/s00114-006-0159-1
19. Chow, S-M. Striupaitis, P. Haskell, N and Gaensslen, R.E. *Time-Dependent Effects of Putrefaction in Bodies on Individualising Striation Marks on Bullets – A Pig Model.* Association of Firearm and Toolmark Examiners Journal, volume 35, number 4, Fall, 2003.
20. Clark, J. 2019, *Oxidation of Aldehydes*.18.8: LibreTexts libraries NICE CXone Expert. https://chem.libretexts.org/Bookshelves/Organic_Chemistry
21. Cockle, D. L. and Bell, L. S. 2019. *The Impact of Trauma and Blood Loss on Human Decomposition,* Science & Justice 59 (2019) 332-336.
22. Connor, M. Baigent, C. and Hansen, E.S. 2018. *Testing the Use of Pigs as Human Proxies in Decomposition Studies.* Journal of Forensic Sciences, September, volume 63, number 5.
23. Contenta, S. 2019. *She's in charge of Canada's first 'body farm' and yes, she knows that's creepy.* The Toronto Star. Viewed 2nd May 2024, www.thestar.com/news/canada
24. Cross, P and Simmons, T. 2010. *The Influence of Penetrative Trauma on the Rate of Decomposition.* Journal of Forensic Science, March 2010, volume 55. number.2.
25. Dent, B.B Forbes, S.L and Stuart, B.H. Review of human decomposition processes in soil. Environmental Geology (2004) 45:576–58
26. Deo, A. Forbes, S.L. Stuart, B.H. and Ueland, M. 2020, *Profiling the seasonal variability of decomposition odour from human remains in a temperate Australian environment*,

Australian Journal of Forensic Sciences, 52:6, 654-664, DOI: 10.1080/00450618.2019.1637938

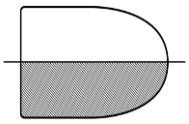
27. Donaldson A.E. and Lamont, I.L, 2013, *Biochemistry Changes That Occur after Death: Potential Markers for Determining Post-Mortem Interval.* LoS ONE 8(11): e82011. https://doi.org/10.1371/journal.pone.0082011
28. Doelling, B., *Comparison of Four Thousand Consecutively Fired, Steel Jacketed Bullets from a 9X18mm Makarov Pistol*, Presented at the Annual Meeting of the American Academy of Forensic Sciences, February, 2001.
29. Doyle, J.S. 2019*, FirearmsID,* viewed 4 June 2020, http://www.firearmsid.com
30. du Preez, G.T. 2003, *Manual to Ballistics and Related Identification Methods*, Institute of Criminology, University of South Africa, Pretoria
31. Dutton, G. 1993, Expert Certificate (s.177), Forensic Ballistics Unit, Physical Evidence Section, reference: J1992/557, J1993/763 and J1994/340, 13 September 1994.
32. Dutton, G. *A Case Study of Forensic Firearms Evidence in the Belanglo Forest 'Backpacker' Murders.* Association of Firearms and Toolmark Examiners Journal, volume 29, number 2, Fall, 1997.
33. Fallingborg, J. 1999. *Intraluminal pH of the human gastrointestinal tract.* Danish Medical Bulletin. Jun; 46(3): 183-196. Viewed 22 March 2023. www.pubmed.ncbi.nlm.nih.gov/10421978.
34. Firearms Review, 2020, viewed 6 June 2020, www.firearmreview.com/beginners-guide-to-reloading/parts-of-a-bullet-cartridge.
35. Forensic Technology, 2014, *IBIS TRAX HD3D MatchPoint.* Training Manual, version 3.0, Document No. TDG-00009. Forensic Technology WAI Inc.
36. Forensic Technology, 2020, *Correlation review with IBIS MATCHPOINT 3.2*, Training video, https://www.youtube.com/watch?v=Mti3NFVNpzo, 28 April 2020.
37. Galloway, A. 1997, *The Process of Decomposition: A Model from the Arizona-Sonoran Desert.* Forensic Taphonomy. The Post-mortem Fate of Human Remains, CRC Press/Haglund, W.D. and Sorg, M.H. (ed).
38. Gill-King, H. 1996, *Chemical and Ultrastructural Aspects of Decomposition*. Boca Raton (FL): CRC Press.
39. Global Security. 2020. *Bullets for Beginners,* viewed 3 July 2020. www.globalsecurity.org/military/systems/munitions/bullets
40. Goff, M.L. 2010. *Current Concepts in Forensic Entomology*. Chapter One, Chaminade University, Hawaii, Forensic Science Program, Springer Science.

41. Grom, T.L. and Demuth, W.E. 2012. *IBIS Correlation Results of Cartridge Cases Collected Over the Course of 500 Firings from a Glock Pistol*. Association of Firearm and Toolmark Examiners Journal, volume 44, number 4, 2012.
42. Hamby J.E, Brund*age,* D.J, and Thorpe, J.W. *The Identification of Bullets Fired from 10 Consecutively Rifled 9mm Ruger Pistol Barrels: A Research Project Involving 507 Participants from 20 Countries.* Association of Firearm and Toolmark Examiners Journal, volume 41, number 2, Spring 2009.
43. Iqbal, M.A. Ueland, M and Forbes, S.L. 2018 *Recent advances in the estimation of post-mortem interval in forensic taphonomy.* Australian Journal of Forensic Sciences. Taylor & Francis Group. hhtps://doi.org/10.1080/00450618.2018.1459840.
44. Ives, J.G. and Rawson, A.E. 1962. *Copper Corrosion. Electrochemical Theory of General Corrosion,* The Journal of the Electrochemical Society, number 6, volume 109, 1962. Council of Australian University Libraries.
45. James, J. 2016. *Corroded Bullets.* The Kiwi Bushman. Viewed 29 July 2023. www.thekiwibushman.co.nz.
46. Karaca, M.A. Kartal, N.D., Erbil, B. Öztürk, E. Kunt, E.E. Şahin, T.T. Özmen, M.M. *Evaluation of Gunshot Wounds in the Emergency Department*. Turkish Journal of Trauma and Emergency Surgery, September 2015, Vol 21, No.4.
47. Kerkoff, W, Hazard, D. and Lopatka, M. 2014. *Atmospheric Corrosion of Bullets and Cartridge Cases as an Indicator of Time since Discharge.* Association of Firearm and Toolmark Examiners Journal, volume 46, number 1, Winter 2014.
48. Knobel, Z. Ueland, M. Nizio, K.D, Patel, D. and Forbes, S.L. 2018. *A comparison of human and pig decomposition rates and odour profiles in an Australian environment.* Australian Journal of Forensic Sciences. 2018.
49. Larrison, R.M, 2006. *Degradation of Fired Bullets and Cartridge Cases in Different Environmental Mediums.* Association of Firearm and Toolmark Examiners Journal, volume 38, number 3, Summer 2006.
50. Leica Microsystems, 2020, *Motorized Forensic Comparison Macroscope Leica FS C*, viewed 15 June 2020, www.leica-microsystems.com/products/light-microscopes/p/leica-fs-c
51. Leser, T.D. Lindecrona, R.H. Jensen, T.K. Jensen, B.B. and Moeller, K. 2000. *Changes in Bacterial Community Structure in the Colon of Pigs Fed Different Experimental Diets after infection with Brachyspira hydrosenteriae.* Applied and Environmental Microbiology, 66(8): 3290-3296, viewed 23 March 2023. www.ncbi.nlm.nih.gov/pmc/articles/PMC92147.

52. Love, E. Association of Firearm and Toolmark Examiners Journal, volume 12, number 1, January 1980.
53. Mann, R.W. Bass, W.M. and Meadows, L. *Time Since Death and Decomposition of the Human Body: Variables and Observations in Case and Experimental Field Studies.* Journal of Forensic Science, 1990, Vol 35, No. 1, 103-111.
54. Mattijssen, E.J.A.T, Witteman, C.L.M, Berger, C.E.H. Brand, N.W. and Stoel, R.D. 2019, *Validity and Reliability of Forensic Firearms Examiners.* Netherlands Forensic Institute, Forensic Science International, 307 (2020), 110112.
55. Matuszewki, S. Hall, M.J. Moreau, G. Schoenly, K.G. Tarone, A.M. and Villet, M.H. 2019, *Pigs vs people: The use of pigs as analogues for human forensic entomology and taphonomy research.* International Journal of Legal Medicine. volume 134.
56. Molina, D. K. and DiMaio, V. J. *Rifle wounds: a review of range and location as pertaining to manner of death*. American Journal of Forensic Medical Pathology. 29(3): 201–205, September 2008.
57. Nichols, R. 2018, *Firearm and Toolmark Identification. The Scientific Reliability of the Forensic Sceince Discipline.* Academic Press. Elsevier.
58. Nichols, R. 2019, *Evaluation of Rank Positions Within Regions of Interest (ROI) for Published NIBIN Leads.* Association of Firearm and Toolmark Examiners Journal, volume 51, number 1, Winter, 2019.
59. Noedel, M. 2009, *Shooting Scene Processing and Reconstruction – Practical Crime Scene Analysis and Reconstruction.* CRC Press. Taylor & Francis Group.
60. Owens, S. 2017. *An Examination of Five Consecutively Rifles Hi-Point 9mm Pistol Barrels with Three Lands and Grooves Left Twist Rifling to Assess Identifiability and the Presence of Subclass Characteristics*, Association of Firearm and Toolmark Examiners Journal, volume 49, number 4, Fall 2017.
61. Pieterse, C.J.S. 2007, Expert Certificate (s.177), Forensic Ballistics Investigation Section reference: J2007/1110, 26 October 2007.
62. Pronpattanapairoj, T. 2023, personal communication, 28 August 2023. Todsapon.Pronpattanapairoj@ultra-ft.com
63. Rao, D. Singh, H and Mowatt, J. *Effects of human decomposition on test fired bullet – Experimental Research.* Egyptian Journal of Forensic Science, 2015, http//dx.doi.org/10.1016/j.ejfs.2015.01.003.
64. Richardson, H.W. 2002, Copper Compounds in *Ullmann's Encyclopedia of Industrial Chemistry*, Wiley-VCH, Weinheim.

65. Sender, R. Fuchs, S. and Milo, R. 2016. *Revised Estimates for the Number of Human and Bacterial Cells in the Body.* Aug 19;14(8): e1002533, viewed 23 March 2023. www.ncbi.nlm.nih.gov/pubmed/27541692
66. Shem, R., and Striupaitis, P., *Comparison of 501 Consecutively Fired Bullets and Cartridge Cases from a 25 Calibre Raven Pistol*, Association of Firearm and Toolmark Examiners Journal, volume 15, number 3, July 1983.
67. Simpson, L. 2020, *Types of Rifling,* Shooting Times, viewed 23 April 2021, https://www.shootingtimes.com/editorial/types-rifling/380473
68. Smith O.C. Jantz, L. Berryman, H.E and Symes, S.A. 1993, *Effects of Human Decomposition on Bullet Striations*, Journal of Forensic Science, JFSCA, volume 38, number 3, May, pp 593-598.
69. Scientific Working Group for Firearms and Toolmarks (SWGGUN), 2013, *Admissibility Resource Kit: Foundational Overview of Firearm Toolmark Identification*. Association of Firearm and Toolmark Examiners viewed 13 June 2020, www.afte.org/resources/swggun-ark.
70. University of Technology Sydney 2017, *AFTER Facility About Us*, viewed 12 August 2020, https://www.uts.edu.au/about/faculty-science/after-facility/about-us.
71. Vass, A.A, Barshick, S.A, Sega, G. Caton, J. Skeen, J.T. Love, J.C and Synstelin, J. J.A. 2002, *Decomposition Chemistry of Human Remains: A New Methodology for Determining the Post-mortem Interval.* Journal of Forensic Science, volume 47(3), p 542 – 553.
72. Vargas, I.T, Diego, A.F, Alsina, M.A, Pavissich, J.P, Pasten, P.A and Pizarro, G.E. 2017. *Copper Corrosion and Biocorrosion Events in Premise Plumbing.* Materials. Volume 10:1036, doi:10.3390.
73. Volburger, T, Song, J & Petraco, N 2015, '*Topography measurements and applications in ballistics and tool mark identifications*' viewed 15 August 2020, https://www.researchgate.net/figure/Striations-on-one-of-several-land-engraved-areas-LEAs-on-a-fired-bullet-The-widely_fig1_291016080.
74. Wilson, H, 2013. *Glossary of the Association of Firearm and Toolmark Examiners*. 6th ed. Version 6.030317.
75. Yuheng, L. Scmidt, H. Wright, A.G. Yu, B. Schyns, G.M. McCormack, U. Cowieson, A.J. Yu, J. Yan, J. Wu, J. Mackie, R.I. and Chen, D. 2022 *Dynamic Distribution of Gut Mircobiota in Pigs at Different Growth Stages: Composition and Contribution.* Microbiology Spectrum, may-June: 10(3),: Viewed 23 March 2023. www.ncbi.nih.gov/pmc/articles/PMC9241710.

Appendix 1: Bullet Types

Bullet type	Description	Image (Doyle, 2019)
Full Metal Jacket	A bullet in which the bullet jacket encloses the entire bullet, with the usual exception of the base. Also called full jacketed, or ball ammunition (Wilson 2013).	 (A cross-sectioned bullet indicating lead core).
Jacketed Hollow Point Bullet (JHP)	A bullet having a metal jacket enclosing a lead alloy core. The entire bullet is enclosed except for the nose, which has a cavity (Wilson 2013).	
Jacketed Soft Point Bullet (JSP)	A design providing for exposure of a portion of the core at the nose of a Jacketed projectile. Also known as a semi-jacketed soft-point bullet (Doyle, 2019).	
Lead Bullet	A bullet formed from lead alloy (Wilson 2013).	
Lubaloy Bullet	A Winchester-Western trade name for a copper bullet coating and jacketing material. This thin coating can be easily scratched away from the surface of the lead (Doyle, 2019).	
Nyclad Bullet	A nylon coated bullet designed to reduce lead emissions (Doyle, 2019).	
Round Nose	A bullet with a hemispherical shaped nose (Wilson 2013).	
'Silvertip' Jacketed Hollow Point	A nickel-plated copper jacket bullet (Doyle, 2019)	

Appendix 2: Specimen Decomposition

Appendix 2.1: Pig Decomposition in Cool Conditions

Image	Description
	Figure A2.1(a): Pig 1 at bullet retrieval day 3
	Figure A2.1(b): Pig 1 at bullet retrieval day 6
	Figure A2.1(c): Pig 1 at bullet retrieval day 9

	Figure A2.1(d): Pig 1 at bullet retrieval day 12
	Figure A2.1(e): Pig 1 at bullet retrieval day 15
	Figure A2.1(f): Pig 1 at bullet retrieval day 18
	Figure A2.1(g): Pig 1 at bullet retrieval day 21

Appendix 2.2: Human Decomposition in Cool Conditions

Image	Description
	Figure A2.2(a): Human donor 1 at bullet retrieval day 3
	Figure A2.2(d): Human donor 1 at bullet retrieval day 9
	Figure A2.2(c): Human donor 1 at bullet retrieval day 12
	Figure A2.2(b): Human donor 1 at bullet retrieval day 15
	Figure A2.2(e): Human donor 1 at bullet retrieval day 21

Appendix 2.3: Pig Decomposition in Warm Conditions

Image	Image	Description
		Figure A2.3(a): Pig 2 (left) and Pig 3 (right) at day 3.
		Figure A2.3(b): Pig 2 (left) and Pig 3 (right) at day 12.
		Figure A2.3(c): Pig 2 (left) and Pig 3 (right) at day 18.

		Figure A2.3(d): Pig 2 at bullet retrieval day 21
		Figure A2.3(e): Pig 2 at bullet retrieval day 24

Appendix 2.4: Human Decomposition in Warm Conditions

Image	Description
	Figure 2.4(a): Human 2 at bullet retrieval day 9
	Figure 2.4(b): Human 2 at bullet retrieval day 12
	Figure 2.4(c): Human 2 at bullet retrieval day 21

Appendix 3: Association of Firearms and Toolmark Examiners (AFTE) Range of Conclusions and the Theory of Identification

i. AFTE Range of Conclusions

The examiner is encouraged to report the objective observations that support the findings of toolmark examinations. The examiner should be conservative when reporting the significance of these observations.

Identification: Agreement of all discernible class characteristics and sufficient agreement of a combination of individual characteristics where the extent of agreement exceeds that which can occur in the comparison of toolmarks made by different tools and is consistent with the agreement demonstrated by toolmarks known to have been produced by the same tool.

Inconclusive:

A. Agreement of all discernible class characteristics and some agreement of individual characteristics, but insufficient for an identification.

B. Agreement of all discernible class characteristics without agreement or disagreement of individual characteristics due to an absence, insufficiency, or lack of reproducibility.

C. Agreement of all discernible class characteristics and disagreement of individual characteristics, but insufficient for an elimination.

Elimination: Significant disagreement of discernible class characteristics and/or individual characteristics.

Unsuitable: Unsuitable for examination.

ii. AFTE Theory of Identification

1. The theory of identification as it pertains to the comparison of toolmarks enables opinions of common origin to be made when the unique surface contours of two toolmarks are in "sufficient agreement".

2. This "sufficient agreement" is related to the significant duplication of random toolmarks as evidence by the correspondence of a pattern or combination of patterns of surface contours. Significance is determined by the comparative examination of two or more sets of surface contour patterns comprised of individual peaks, ridges and furrows. Specifically, the relative height or depth, width, curvature and spatial relationship of the individual peaks, ridges and furrows within one set of surface contours are defined and compared to the

corresponding features in the second set of surface contours. Agreement is significant when the agreement in individual characteristics exceeds the best agreement demonstrated between toolmarks known to have been produced by different tools and is consistent with agreement demonstrated by toolmarks known to have been produced by the same tool. The statement that "sufficient agreement" exists between two toolmarks means that the agreement of individual characteristics is of a quantity and quality that the likelihood another tool could have made the mark is so remote as to be considered a practical impossibility.

3. Currently the interpretation of individualization/identification is subjective in nature, founded on scientific principles and based on the examiner's training and experience.