The Recreation of Wound Patterns Using Various Tissue Simulants for Crime Scene Reconstruction

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The Recreation of Wound Patterns Using Various Tissue Simulants for Crime Scene Reconstruction

by

Breanne R. Steimle
Chemistry B.S., Forensic Science M.S. Candidate

A Project Report in Forensic Science

Submitted in Partial Fulfillment Of the Requirements For the Degree of Master of Science Spring 2020

Buffalo State College State University of New York
Abstract

Within the field of forensic science, there are limited reliable methods for the simulation of pattern injuries on human skin and tissue that may aid in aspects of crime scene reconstruction. The tissue simulant must be of sufficient integrity for recording blunt force trauma and bite mark impressions, electrocution, cutting, and gunshot wound related injuries for the purpose of re-enactment, court exhibition, and distance determination. For wound reenactments (such as blunt force trauma, bite mark impressions and electrocution), dead skin and tissue from human cadavers do not show wounding patterns that would occur on live tissue. This study examines different tissue simulants for the recreation of wound patterns without the use of live animals. For each wound reenactment, tissue simulants (such as ballistic soap, ordnance gelatin and “ballistic dummies”) were penetrated and wound patterns were formed and were analyzed in detail. Penetration depth, as well as the path shape, were analyzed for both stabbings and gunshot wounds. For the electrocution wound pattern, a Taser was tested on ballistic soap.

Photography was used to document findings with the various tissue simulants. In this research, comparison and stereo microscopes were also used to observe the different wound patterns in detail and compare the weapon used to the wound it formed. The wound patterns were also compared with patterns observed during other injury simulations, found in the literature on human remains to determine which simulant was the most ideal for recreating several types of wound patterns. This is a means by which the events of a crime can be visualized and validated and then be brought before a jury to help understand how a pattern injury occurred. This research provides insight to the area that is relatively unexplored in crime scene reconstruction by helping to identify the type of injury and weapon, based on the appearance of wounds.
Keywords: Tissue simulants, wounds, wound patterns, sharp force, ballistics, blunt force, reconstruction, electrocution, bite mark, analysis, cause of death

Research question: Can different types of tissue simulants recreate the appearance of wounds (e.g. gunshot, stabbings, electrocution, bite marks, and blunt force) that are accurately comparable to human tissue trauma?
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Master of Science

Fall 2019

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Chapter One: Introduction

Crime scene reconstruction is an important component in solving a crime; utilizing factors such as physical evidence and witness accounts to formulate theories about how the crime occurred. These factors lead to confirmation or refuting of specific events that occurred during the crime and the order in which these events occurred. Crime scene reconstruction is comparable to putting a jigsaw puzzle together without having the picture on the box to look at; the pieces within the puzzle reference the specific events that happened during the crime, as well as events that preceded and succeeded the crime without actually knowing how the crime was committed. The physical evidence that is collected may include facts about the perpetrator or victim, such as documenting the blood or footprint trails that lead into and out of the premises. Defensive wounds found on the victim, belongings missing from the premises may provide theories on the events preceding the crime. The saying “the evidence tells the story” is often an accurate statement. If ten witness statements were taken, often there will be ten different accounts of the crime that committed, leading to an abundance of possible theories about what happened. The evidence that is present at a crime scene and verified after analysis helps to reduce the number of possibilities of what happened that are, hopefully, more accurate (Staletovich, 2018). Crime scene reconstruction is an important component of court testimony to help tell the story of the crime to the judge and jury. When pieces of the puzzle are absent, theories are produced based on the evidence provided. These theories are then tested to validate or disprove what happened. Was the victim facing the suspect when shot in the front of the
shoulder or was the victim running away and was shot in the back of the shoulder? One major piece of the puzzle that is important for the reconstruction of a crime is the cause of death of the victim (Chisum and Turvey, 2007).

The manner of death divides the events surrounding how a victim died into categories of natural, accidental, suicide, homicide or undetermined. The cause of death is a condition resulting in a human’s death and determined by a medical examiner. During an autopsy, the medical examiner observes any external wounds that demonstrate injuries that the victim may have received that may indicate the possible cause of death. For example, if there were penetrating wounds on the victim’s chest, the medical examiner would examine the entire wound pattern to determine if the weapon used was a gun or a sharp instrument. If gunpowder was found around the wound and/or a bullet is found within the penetrating wound cavity, then it is determined that the cause of death was a gunshot wound. The cause of death is an important aspect of the crime scene reconstruction because it can assist in determining what type of weapon was used. One may infer stab wounds are inflicted by suspects that need to be in close contact with the victim, whereas a bullet may be fired from any distance. The location of the stab wound may also provide additional evidence against a suspect, based on if the wound was inflicted by left or right handed person (Wexelman, et al, 2013).

Human skin is the body’s largest organ that performs many functions, the most important of which is an integumentary system that provides the overall body protection from environmental, chemical, and physical harm. The integumentary system consists of skin and its appendages that protect the body from internal and external damage. The types of appendages that are included within this system in the animal kingdom are hair, scales, feathers, hooves, and
nails. This system retains the water within the body, as well as excrete waste and regular body temperature (Martini, et al, 2013).

The skin is made of three layers that play different roles in protecting the body; the epidermis, dermis, and hypodermis, shown in Figure 1.1 (Martini, et al, 2013). The epidermis is the outer-most layer of skin composed of four or five layers of closely packed epithelial cells. This is the thinnest layer of skin that does not have any blood vessels within it. There is a high abundance of keratin within this layer of skin, which provides support to the hair and nails, as well as providing density and water-resistance properties. The dermis is known as the core of the integumentary system, containing blood and lymph vessels, nerves, hair follicles and sweat glands. This layer has many protein fibers that influence the overall physical properties of the skin, such as elastin (elasticity) and collagen fibers (tensile strength). The hypodermis is the layer of skin that connects the entire skin structure to the underlying fat, tissue, and bones. The function of this layer of skin serves as a fat storage area, providing insulation and cushioning (Martini, et al, 2013).
The type of wound that is inflicted on a human body may suggest possible weapons that produced the wound. There are three categories of wounds: non-penetrating wounds, penetrating wounds, and miscellaneous wounds. Objects or weapons that do not result in breaking of the skin cause non-penetrating wounds. Even though these wounds may have the appearance that the skin is broken, the wounds are not deep enough to have penetrated the underlying connective tissue. These wounds consist of abrasions, lacerations, contusions, and concussions. Images of these wounds are shown in Figures 1.2 a-d (Internet) (Farlex, et al, 2003).

Abrasions are a result of scraping or wearing of the skin past the epidermis layer, also known as scrapes. Falling on the sidewalk and obtaining a “skinned knee” or scrapes on the palms and knees are considered abrasions. These types of wounds are commonly found on young children who are learning to use outdoor recreational equipment, such as a bicycles or roller skates (Farlex, et al, 2003).

Lacerations are tears that separate the skin, but not with enough force to tear through the entire dermis layer. This wound occurs when the skin is compressed or moved out of place by an external force. Lacerations are a result of a blow from a blunt instrument or from a fall onto a hard surface that results in splitting of the skin (Farlex, et al, 2003).

Contusions are also known as bruises, or an injury to the skin resulting in the discoloration without breaking through the skin. The blood from the broken vessels accumulates around the affected area, producing tenderness and swelling. Contusions may also be a result from a blunt force trauma such as bumping into an object or being hit with a blunt instrument. Concussions are wounds resulting from a blunt instrument or a hard surface contacting the head. This type of head injury affects brain functioning and may be serious if not treated. Although
there is cerebrospinal fluid surrounding the brain, acting as a cushion for possible impacts or forces, the fluid may not be able to absorb the impact if a sufficient force struck the head (Brands, et al, 2019).

Figure 1.2 a-d: Images of non-penetrating wounds; laceration (top left), abrasions (top right), contusions (bottom left) and concussions (bottom right). (Google Images).

Penetrating wounds are a result of trauma to the body that breaks through the full thickness of skin, as well as the underlying tissue and organs. Types of penetrating wounds
consist of incised wounds, stab wounds, chop wounds, surgical wounds, and gunshot wounds, shown in Figure 1.3 a and b. A stab wound is a result of penetrating trauma to the skin and the surrounding tissue caused by a sharp instrument, such as a knife. These types of wounds are deeper than they are wide and may affect bones, organs, or blood vessels that if untreated, could be fatal. A surgical wound is an incision or cut resulting from a scalpel during surgery. These wounds would also involve suture patterns from stitches or staples to help close the wound and control environmental factors from affecting the body (Brands, et al, 2019).

Figure 1.3 a, b, and c: Images of penetrating wounds such as surgical wounds (left), stab wounds (middle), and gunshot wounds (right). (Google Images).

Miscellaneous wounds are either a combination of penetrating and non-penetrating wounds, or fall into a different category all together. Thermal wounds, chemical wounds, bites, and electrical wounds all fall into the miscellaneous category and are shown in Figure 1.4 a-d.
Thermal and chemical wounds are types of burns that result from making contact with extreme temperatures or caustic chemicals, respectfully. Thermal wounds may result in burns or frostbite, whereas chemical wounds may cause dermal or lung damage. The types of chemicals that cause chemical wounds are very strong acids or bases that are able to burn or corrode human skin and tissue; for instance concentrated hydrofluoric acid. Bite wounds may be a combination of penetrating and non-penetrating wounds, potentially including bruises and tears. These types of wounds are contingent on sufficient force for an animal to bite down on the body, and the sharpness of teeth to penetrate into the skin (Brands, 2019). Electrical wounds are a result of high voltage currents passing through the body. This type of wound usually appears as burns and bruises at the location of the affected area, however, they can also appear as tears if the electrical current was of extremely high voltage (Anonymous, 2011).
The purpose of this study was to determine if wounds could be accurately reproduced on a non-living media with sufficient accuracy to replicate the appearance of the wounding instrument, as it would appear in living tissue. Before this question can be answered, one must examine the different properties of human skin and tissue. These physical properties affect the production and appearance of wounds. The major tissue properties that effect the formation of wounds are the conductivity, elasticity, tensile strength, density, the nature of the underlying bony support, and the capacity to absorb energy (Cohen, et al, 1977).

Thermal conductivity is the ability to transport energy due to a random molecular motion across a temperature gradient. Materials that have a high conductivity, such as metal, are efficient at conducting heat as well as conducting electricity. As a reference material, pure water has a
thermal conductivity of 0.627 W/mK (Watts per meter Kelvin, the SI unit for thermal conductivity). It was determined, based on the values in Table 1.1, human skin and tissue are the least conductive components of the body, and have a resistivity of up to 500,000 Ω (ohms). Human tissue and skin have a lower thermal conductivity than that of water, as shown in Table 1.1 (Cohen, 1977). Due to this effect, when skin is dampened, the resistivity of skin decreases from 500,000 Ω to 1000 Ω (Cohen, et al, 1977).

Table 1.1: Thermal conductivity of human tissue

<table>
<thead>
<tr>
<th>Human Tissue</th>
<th>Thermal Conductivity K (W/mK)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whole blood</td>
<td>0.492 +/- 0.009</td>
</tr>
<tr>
<td>Fat</td>
<td>0.201-0.217</td>
</tr>
<tr>
<td>Epidermis</td>
<td>0.209</td>
</tr>
<tr>
<td>Dermis</td>
<td>0.293-0.322</td>
</tr>
</tbody>
</table>

Dermis has 60% the conductivity of blood, fat has 41% the conductivity of blood, and the epidermis has 42% the conductivity of blood.

Elasticity of an object is the ability to stretch that material to reach its full range of movement without restriction. An ideal example would be the stretching of a rubber band. When the rubber band is released from its stretched form, it contracts back to its original form. Elastin is a protein within the connective tissue that gives human tissue and skin elasticity. Human skin has an elasticity of 2.0x10^6 N/m^2 (Newton per meter squared), whereas a non-elastic metal such as aluminum has an elasticity of 6.0x10^10 N/m^2. The elasticity value represents the amount of force needed to give materials their elastic properties; therefore, a large elasticity value represents a
material with less elastic properties, or more force that is needed to show a material’s elastic properties (Sanders, et al, 1973).

Tensile strength is also an important physical property of human skin and tissue when producing wound patterns. Tensile strength is the maximum stress or stretching that a material can withstand without breaking. An example of measuring the tensile strength of human tissue and skin would be to observe drawing and quartering. In the 13th century in England, a punishment for treason would be quartering, which included the guilty party having all four limbs being tied to four different horses and have them spurring in different directions until the limbs were broken and separated from the rest of the body. Human skin has a tensile strength of 15-20 MPa (mega Pascal’s), whereas a material such as granite has a tensile strength of 4.8 MPa. Mega pascals is the SI unit for pressure and one MPa is equivalent to 145.038 pounds per square inch (psi). Tensile strength and elasticity have a direct relationship; if a material has a large tensile strength, then the material also has elastic properties. As a reference to materials used in everyday life, rubber has a tensile strength of 15 MPa, similar in value to that of human skin (Sanders, et al, 1973).

Compression strength is the maximum tension or reduction in size that the material can withstand without being broken. An example would include observing a material being compressed by a hydraulic press. Human tissue has a compression strength of only 0.69 MPa, whereas a material such as bone has a greater compression strength of 150 MPa. Density of a material is important when recreating various wound patterns in human tissue. Because over 70% of human tissue is made of water, the densities of the two materials are very similar; human tissue has a density of 1.27 g/mL and water has a density of 1.0 g/mL. These physical properties
of human skin and tissue are important when recreating wound patterns. The difference in physical property may result a different appearance of a wound pattern (Sanders, 1973).

One of the major difficulties with recreating accurate wound patterns is that it is difficult to use live humans or cadavers because of ethical concerns. Another concern is that once the body dies, the skin and tissue does not have the same physical properties as live human tissue does. In order to reconstruct various types of wound patterns, a material must be found that has the same or similar physical properties to living human skin and tissue. Such materials are called tissue simulants. The Merriam-Webster dictionary describes a tissue as “an aggregation of morphologically similar cells and intercellular matter acting together to perform one or more specific functions in an organism”. The dictionary also defines a simulant as “a physical model resembling another part in structure or function”. Based on these definitions it is summarized that a tissue simulant is a material that accurately represents or replicates one or more physical properties of human tissue and skin. This project looked at several different types of tissue simulants to observe which were suitable in replicating specific types of wound patterns (Kneubuehl, et al, 2011).

There are many materials that can form wound patterns, however those patterns may greatly differ from those made in human skin. There are three major requirements in order to be considered a tissue simulant. The first is reproducibility in injury pattern production. The second requirement for a material to be considered a tissue simulant is that the wound produced should provide information related to the direction of motion of the cutting instrument and otherwise mimic the effects in live human tissue. If all of the variables are constant when recreating the wound in a material, the wound patterns should be identical or very similar as the wound pattern produced in human tissue. The third requirement for being considered a tissue simulant is that
the physical parameters along the wound channel must closely encounter that of real life. If a weapon produced a circular shaped wound that measured 3 mm in diameter and a wound cavity 100 mm deep in human tissue, then under the same conditions the wound diameter and cavity should also have similar values when the wound is produced in a tissue simulant. Although not a requirement, the cost, availability, and ease of use must also be in consideration when finding an ideal tissue simulant. In a criminal investigation, there may only be one wound pattern found on the victim, however there may be numerous variables that need to be considered and replicated in order to verify how the specific wound was created (Kneubuehl, et al, 2011).

Several materials have been suggested as possible tissue simulants. Their accuracy and reproducibility in recording varying types of injury mechanisms have been explained in varying degrees. There may be subtle details of relevance in the reconstruction that need to be replicated in the simulant. One of the first types of materials that was used as a tissue simulant to reconstruct wound patterns was porcine or pig skin. The use of this material for wound reconstruction began in the late 19th century. Pigs have a thick epidermis layer with similar structure and function to human skin, as well as similar tissue framework. Porcine skin also has a high content of elastin fibers and is sparsely hair-coated, similar to human skin. The similarities of physical properties between porcine skin and human skin would theoretically result in similar appearances in wound patterns as many living and non-living animals were experimented on for the purpose of wound pattern reconstruction. Pig skin can be readily obtained from a butcher and few ethical considerations are involved (Kneubuehl, et al, 2011).

Other materials such as wood panels were used to test penetration capability of projectiles. It was quickly determined that these materials alone were only able to satisfy a few physical properties of human tissue and therefore were not significantly used anymore for wound
reconstruction. Wood panels would be used to reconstruct wound patterns in bone, however the surrounding tissue of the bone was not considered, resulting in different appearances of wound patterns from those produced in human tissue. Water tanks are used for collecting the bullets fired through evidence weapons with minimal damage. The water tank, however, provides no information related to the ammunition behavior in tissue (Kneubuehl, et al, 2011).

The most common types of materials that are currently used as tissue simulants are ballistic gelatin, ballistic soap, and porcine skin. There are still problems with using these types of materials (some of which will be illustrated by some of the experimental results) as tissue simulants and therefore attempts have been made to replace them with more reliable materials. These types of tissue simulants need special storage conditions of a temperature around 4°C in order to maintain the materials shape and density. If the specific storage conditions are not maintained then there is a likely chance of mold growth, which contaminates and can potentially alter the overall performance of the material. The materials used to manufacture these types of tissue simulants can be expensive, especially in a laboratory were ballistic gelatin is often used. An extensive period of preparation is required before the materials can be used. Finding a suitable, low cost tissue simulant for reproduction of gunshot wounds encompassed the first part of this study (Kneubuehl, et al, 2011).

The types of artificial gunshot wounds that have been most studied are gunshot wounds produced in ballistic gelatin and ballistic soap. The gelatin that is used to produce ballistic gelatin is found in a powder form, derived from collagen which is extracted from pig, horse, or cow body parts. Collagen is made of a long string of amino acid (glycine, proline, and an additional acidic amino acid) tightly packed to form a triple helix structure, shown in the bottom left of Figure 1.5 (Baguley, 2015). When bone and tissue of various animals are heated,
the collagen is extracted and denatured by heat. This irreversible chemical process results in a solution of gelatin. By adding warm tap water to the gelatin solution in a specific ratio of ninety percent water and ten percent 250 bloom gelatin powder by weight, and cooling the mixture to 4°C, the long chain structures of the liquid gelatin form hydrogen bonds with the water and form a triple helix structure, similar to collagen. The addition of the hydrogen bonds and the maintained temperature results in a solidified gelatin (Huggins, 1957).

Figure 1.5: The chemical reaction of the formation of gelatin from collagen found in animal bone and tissue. (Baguley, C. M. (2015, September 10). Appliance science: The firm chemistry of gelatin. Retrieved from Cnet: https://www.cnet.com/news/appliance-science-the-firm-chemistry-of-gelatin/).

Ballistic gelatin has been previously used in ballistic studies as a tissue simulant, however it has not been extensively used in the replication of other modes of injury beyond gunshot wounds. There have been recent television shows that use ballistic gelatin as a tissue simulants for producing wound patterns. These television shows include “Myth Busters” and “Deadliest Warrior”. One of the major problems is that these shows assume that the ballistic gelatin will produce similar wound patterns to live tissue and skin, even though this material has only been
used to reconstruct ballistic wounds. These televised reenactments can afford the use of very expensive types of “ballistic dummies” consisting of blood, bone, and animal organs, shown in Figure 1.6 (Internet). This may be suitable for some type of blood spatter experiments if the weapon comes in contact with simulated organs and bone masses. This type of tissue simulant is extremely expensive and therefore not ideal for use in a forensic field, especially if a large supply of tissue simulants is needed to reconstruct wound patterns.

![Figure 1.6: A torso representation of a tissue simulant “ballistic dummy” used during television shows such as “Deadliest Warrior” and “Myth Busters”. (Google Images).](image)

Ballistic gelatin was developed by Martin Fackler (Jussila, 2004) in order to observe the effects of bullet wounds in simulation. The expansion of projectiles, as well as penetration depths were evaluated. The most common formula that is currently used to prepare ballistic gelatin is ten percent ordnance gelatin. The preparation of the ballistic gelatin is mentioned in Appendix I. Ten percent ordnance gelatin is prepared by dissolving one part 250A bloom gelatin
into nine parts warm water. The bloom value is the strength of the gelatin or the hardness of the gelatin. The test determines the weight in grams needed by a plunger to depress the surface of the gelatin by 4 mm without breaking at a specific temperature (Schrieber & Gareis, 2007). The gelling power of gelatin is determined by the bloom value and concentration of gelatin; the larger the bloom value, the more firm the consistency of gelatin when solidified. If not prepared correctly, the gelatin will have a consistency similar to “Jell-O” gelatin rather than of ballistic gelatin (Melbourne, et al, 2019).

This project produced and observed various types of wound patterns in different materials. Some materials that were used in this research are currently known to be reliable tissue simulants, however other materials were compared to determine which material would be most ideal for recreating accurate wound patterns. The types of wounds patterns that were produced throughout this research were gunshot wounds produced from handguns, stab wounds and slice wounds produced from knives, human bite marks, blunt force trauma wounds produced from glass bottles, and electrical wounds produced from a Taser-like device.
Chapter Two: Ballistic Wounds

Introduction

Ballistic wounds are a result of the physical movement and properties of a projectile (fired bullet) impacting a material. As in any wound pattern formation, there are a great number of variables involved. The type of ammunition used, the distance from weapon to target, and the location on the body where bullet penetration occurs are of great importance for changing the appearance of a ballistic wound. Other important variables may include the yaw of the fired bullet, the length of the barrel, the shape of the bullet, the ability to fragment, the velocity, type of smokeless powder, and the angle of impact when it enters and exits the target. These different variables influence the size and shape of the entrance and/or exit wounds, as well as the extent of tearing around the entrance wound, the penetration depth, and the presence of tattooing or stippling (Murtha & Wu, 2012).

Handguns are the most common type of firearm to be used in a crime and the type of weapon that produces the largest number of homicidal deaths. For this reason, gunshot wounds produced from projectiles fired out of handguns were investigated in this research. A representative type of ammunition used in handguns are shown below in Figure 2.1 (Internet)
When the slide of the handgun is pulled back and released, the cartridge is pushed into the chamber of the barrel. When the trigger is pulled, the hammer strikes the firing pin, igniting and mixing the primer powder within the primer. The primer includes lead stypnate (the initiator), antimony sulfide (the fuel), and barium nitrate (the oxidizer) which will result in a small explosion. The flame from the explosion travels through the flash hole and ignites the propellant or gunpowder. When the pressure of the ignited powder reaches its maximum, it causes the bullet to push out of the cartridge and move through the barrel (Di Maio, et al, 1999).

This research looked at wound patterns produced from seven different types of ammunition: 9 mm Luger round nose bullets, 9 mm Luger hollow point bullets, .40 Smith and Wesson round nose bullets, .40 Smith and Wesson hollow point bullets, .40 Smith and Wesson hollow point law enforcement issued bullets, .45 auto round nose bullets, and .45 auto hollow point bullets. Physical properties of the types of ammunitions, as well as some background
information are mentioned in Appendix III. These types of ammunitions used throughout this project was due to the ease of accessibility to obtain the ammunition. The 9 mm Luger ammunition is the most common type of ammunition used due to the ease of access to this type of ammunition (Krause, 2015). All types of ammunition used in this project are within the top twenty list of calibers used (Brandon, et al, 2015).
Procedure from Pig Skin and White T-shirt Attached to a Cardboard Panel

Simulants

Porcine skin was hung by a target clip in an indoor gun range and a 9 mm Glock 17 gen 4 was fired using 9 mm ball, or round nose ammunition, and 9 mm hollow point bullets to produce contact wound patterns. An experienced shooter, Cliff Schlemmer, with knowledge of how to operate the handgun fired the firearm. Mr. Schlemmer is an employee at Wolcott Guns Inc. in Depew, NY. This business sells ammunition and firearms, as well as including indoor firing ranges of 25 yards and 50 yards in length. Samples of porcine skin was obtained from a local butcher shop (Whole Foods), frozen and thawed before the fired 9mm bullets penetrated the skin. The porcine skin was separated from the abdomen section of the pig and frozen without additives or preservatives. The skin samples were 5 mm thick due to the skin itself and the underlying connective fat. A side view of the thawed pig skin is shown in Figure 2.2. Two shots were fired into the porcine skin using a 9 mm round nose and a 9 mm hollow point cartridge. Tattooing of unburned gun powder, as well as documentation of the entrance and exit wound patterns produced were observed and documented. For accurate results, all other variables except the type of ammunition used were remained constant, including the type of firearm used to fire the 9 mm rounds. The properties and variables of the 9 mm round nose and 9 mm hollow point bullets are shown in Table 2.1.
White t-shirts were placed around cardboard panels and hung on target clips, similar to the set-up for the porcine skin. Several 9 mm round nose and 9 mm hollow point bullets were fired using the same firearm as in the porcine skin study, and contact wound patterns were
produced. Two shots were fired into the t-shirt simulant using both the 9 mm round nose and 9 mm hollow point ammunition. The distance of firing from the end of the barrel to the target was approximately 5 cm. These wound patterns are shown in Figure 2.4. It was determined later in this study, also mentioned below, that the distance was approximately 10 cm, producing distance wound patterns. The tattooing of the unburned gunpowder around the wound patterns were photographed, measured, and compared to those produced in the porcine skin.

Figure 2.4: Wound patterns produced from fired 9 mm round nose (right) and 9 mm hollow point (left) bullets in a white t-shirt attached to cardboard backing fired at near contact distance.
Results from Pig Skin and White T-shirt Attached to a Cardboard Panel

Both the fired 9 mm standard and 9 mm hollow point bullets produced distinctive wound patterns in the porcine skin and left tattooing around the entrance wound, shown in Figure 2.3 a and b. Although the porcine skin was from a butchered pig, the skin still had some elastic properties based on the wound patterns formed from both types of 9 mm rounds. Fired 9 mm standard bullets produced irregular shaped, small entrance wounds with some tearing around the edges. At first glance, the entrance wounds appeared slit-like, similar to possible knife wounds produced by a small blade. The wound pattern produced was elongated and rectangular in shape. An closer examination of the entrance wounds are shown in Figure 2.5. It was observed that there was tattooing present around the edge of the entrance wound, however there was little unburnt powder, or gunshot residue. Measurements of the entrance wounds and tattooing are summarized in Table 2.1.

Figure 2.5: Entrance wounds produced from fired 9 mm round nose bullets in thawed porcine skin from near-contact distance.
The exit wound dimensions produced by the fired 9 mm bullets were recorded, even though tattooing and soot was of main concern. The exit wounds produced from a fired 9 mm standard round bullet was larger in diameter than that of the entrance wound and appeared to have more tearing around the edge of the wound. Shown in Figure 2.6, the fired 9 mm round nose bullets produced exit wounds that appeared to be square-ish in shape. Measurements of the exit wounds are summarized in Table 2.1.
The 9 mm hollow point bullets were also fired into the porcine skin to compare wound patterns produced. As shown in Figure 2.7, the fired 9 mm hollow point bullets produced more regular or circular-shaped entrance wounds with little to no tearing around the edge of the wound patterns. As mentioned in Table 2.1, the entrance wound produced from the fired 9 mm hollow point bullets were larger in diameter and more regular in shape than the entrance wounds produced from the fired 9 mm round nose bullets.

Different tissue simulants were fired at using 9 mm round nose bullets from a distance of 25 yards to compare the different wound patterns produced in different materials by the same type of ammunition. Ballistic gelatin and ballistic soap, two of the most common types of tissue
simulants used for ballistic studies were fired into, as well as PermaGel. Permagel is known as a more stable type of synthetic ballistic gelatin manufactured by Clear Ballistics, and is more translucent. The ballistic soap and ballistic gelatin were prepared previous to being fired into. The preparation of these materials is mentioned in Appendix I. The PermaGel was purchased and shipped in a block formation ready to be fired into. Three 9 mm round nose bullets were fired into each of the three tissue simulants and the wound patterns produced were documented and measured.

Table 2.1: Summary of wound patterns produced from fired 9mm bullets into porcine skin at near-contact distance using a Glock 17 gen 4.

<table>
<thead>
<tr>
<th>Wound Type</th>
<th>Entrance Wound</th>
<th>Longest Soot Distance from Entrance Wound</th>
<th>Exit Wound</th>
</tr>
</thead>
<tbody>
<tr>
<td>9mm round nose shot 1</td>
<td>W: 4mm H: 4mm</td>
<td>6.0 cm</td>
<td>W: 7mm H: 11mm</td>
</tr>
<tr>
<td>9mm round nose shot 2</td>
<td>W: 2mm H: 5mm</td>
<td>7.5 cm</td>
<td>W: 6mm H: 8.5mm</td>
</tr>
<tr>
<td>9mm hollow point shot 1</td>
<td>W: 5mm H: 5mm</td>
<td>6.7 cm</td>
<td>W: 21mm H: 18mm</td>
</tr>
<tr>
<td>9mm hollow point shot 2</td>
<td>W: 4mm H: 6mm</td>
<td>6.0 cm</td>
<td>W: 11mm H: 7mm</td>
</tr>
</tbody>
</table>

W= width of wound; H= height of wound
Figure 2.7: Entrance wounds produced from fired 9mm hollow point bullets in thawed porcine skin from near-contact distance.

The exit wounds produced from the fired 9 mm hollow point bullets were also observed and analyzed, as shown in Figure 2.8. Similar to the entrance wounds produced from the fired 9 mm hollow point rounds, the exit wounds were more regular or circular in shape than the exit wounds produced from the fired 9 mm round nose rounds. The exit wounds produced from the hollow point bullets were also larger in diameter than the fired round nose rounds, as mentioned in Table 2.1.
Figure 2.8: Exit wound patterns produced from fired 9 mm hollow point bullets into porcine skin from near-contact distance.

The white t-shirt attached to cardboard backing were used in order to better observe the unburnt gun powder and tattooing pattern from the fired 9 mm rounds. All the same variables were used when firing at the white t-shirt as when the porcine skin was fired at. Two 9 mm round nose bullets were fired into the right side of the t-shirt and two 9mm hollow point bullets were fired into the left side of the t-shirt, shown in Figure 2.9. A closer look at each wound pattern, shown in Figure 2.9 and Figure 2.10 shows that the tattooing and unburnt gunpowder patterns are representative of fired 9 mm round nose and 9 mm hollow point rounds. It was observed that there was a greater amount of tattooing produced by the fired round nose bullets than produced by the fired hollow point. However, it was also observed that there was more unburned gunpowder present from the fired hollow point bullets than the fired round nose cartridges. A close look at the tattooing patterns produced from the fired hollow point bullets revealed that there were swirl patterns turning in a counter-clockwise position. The swirl patterns helped to
show that the bullet was fired from a firearm with a left-twist barrel and was rotating along its x-axis as it penetrated through the t-shirt attached to cardboard backing. These observations can be observed from Figure 2.9 and Figure 2.10 and Figure 2.11 a and b, and from the measurements summarized in Table 2.2. To confirm the observation that the bullet was spinning with a left-hand twist (counter clockwise), it was found in literature that the direction of twist inside the barrel of the Glock 17 is left-handed and have six lands and grooves (Di Maio, 1999). The entrance wounds themselves were relatively circular in shape produced from both fired 9 mm round nose and hollow point bullets. The entrance wounds produced from fired 9 mm round nose bullets were slightly smaller in diameter compared to the wound pattern produced from the fired 9mm hollow point rounds. As shown in Table 2.2, the diameter of the entrance and exit wounds for both the fired 9 mm bullets were similar in size and only differed in the tattooing patterns. These powder patterns mirror the differences in smokeless powder composition between different types of ammunition as is reflected by distance between the gun muzzle and the target substrate. Observations and measurements will focus on the differences between bullet caliber and bullet configuration and the subsequent wound cavity produced in the different tissue simulants.
Figure 2.9: Closer view of tattooing and unburned gunpowder pattern produced from fired 9 mm round nose cartridges.

Figure 2.10: Closer view of tattooing and unburned gunpowder pattern produced from fired 9 mm hollow point cartridges.
Figure 2.11 a and b: Close-up observation of a left-twist tattooing pattern around the entrance wound produced on the white t-shirt from the 9 mm hollow point round fired from a near-contact distance. A sharper focus of the tattooing patterns and threads demonstrating a left-hand twist from the right image.

Table 2.2: Summary of wound patterns produced from fired 9mm bullets into a white cotton t-shirt around a cardboard panel at near-contact distance using a Glock 17 gen 4.

<table>
<thead>
<tr>
<th></th>
<th>Entrance Wound Dimensions</th>
<th>Tattooing diameter around entrance wound</th>
<th>Longest Soot Diameter from Entrance Wound</th>
<th>Exit Wound Dimensions</th>
</tr>
</thead>
<tbody>
<tr>
<td>9 mm round nose shot 1</td>
<td>W: 5 mm H: 6 mm</td>
<td>2 mm</td>
<td>6.1 cm</td>
<td>W: 3 mm H: 5 mm</td>
</tr>
<tr>
<td>9 mm round nose shot 2</td>
<td>W: 7 mm H: 5 mm</td>
<td>3 mm</td>
<td>6.1 cm</td>
<td>W: 4 mm H: 5 mm</td>
</tr>
<tr>
<td>9 mm hollow point shot 1</td>
<td>W: 6 mm H: 8 mm</td>
<td>2 mm</td>
<td>7.4 cm</td>
<td>W: 3 mm H: 5 mm</td>
</tr>
<tr>
<td>9 mm hollow point shot 2</td>
<td>W: 6 mm H: 5 mm</td>
<td>2 mm</td>
<td>6.8 cm</td>
<td>W: 5 mm H: 6 mm</td>
</tr>
</tbody>
</table>
Discussion on pig skin and white t-shirt attached to a cardboard panel

Various types of potential tissue simulants, as well as different types of variables were used throughout this ballistic study to produce wound patterns. The pig skin and white t-shirt attached to a cardboard panel were performed primarily for distance determination based on the wound patterns and powder distribution that were produced. The first part of the ballistic study was to replicate near-contact wound patterns as well as compare the wound patterns produced in porcine skin to a t-shirt attached to cardboard backing. In the different media used, the size of the entrance hole, the presence of abrasion collar, deposition with and patterns of gunpowder and soot were important. In comparing the wound patterns from the different materials, there was observed to be less tattooing around the wound patterns in the porcine skin than the t-shirt. The porcine skin was frozen and thawed before the material was fired into and therefore was damp on the surface. This effect could, along with the fact that porcine skin had a greater number of wrinkles, explain why there was less tattooing and gunshot residue than found on the white t-shirt. It was observed that the diameters of the entrance wounds produced in the porcine skin and white t-shirt were very similar in size, as well as the exit wounds. There was stellate tearing around the entrance wounds produced in the porcine skin from the fired 9 mm round nose bullets. Stellate tearing is the tearing that forms from the gases that are expelled from the barrel of a firearm along with the bullet and their interaction with material such as human skin. The gases that are released from the barrel were produced by the combustion of the propellant and is released in a highly compressed state (Di Maio, 1999). Stellate tearing that was observed in the porcine skin is observed in Figure 2.5. The stellate tearing observed in the porcine skin within this study is referenced to stellate tearing in literature (internet) in Figure 2.5b. The main
difference between the wound patterns produced in the porcine skin and white t-shirt attached to cardboard backing was the radius of tattooing and gunshot residue around the entrance wounds. This observation is shown from the measurements in Tables 2.1 and 2.2. Figures 2.6 and 2.8 are images of the exit wounds produced from 9 mm Luger round nose and hollow point bullets produced in the porcine skin. In comparison, the hollow point bullets produced circular-shaped wounds and did not appear to have any difficulties penetrating through the underlying fat attached to the porcine skin.

In addition to the porcine skin used as a potential tissue simulant, the white t-shirt on a cardboard panel was also used. Because the porcine skin was still damp from being frozen and thawed, the gun shot residue did not stick to the material as well, altering the overall wound pattern to make it appear like a more distant target. The white t-shirt also assisted in observing the tattooing and stippling pattern better due to the significant contrast between the color of the shirt and the color of the gunpowder. Overall, the wound patterns produced in the porcine skin and white t-shirt attached to cardboard backing were similar, however the tattooing and stippling patterns were better observed on t-shirt attached to cardboard backing. Some research has been conducted on the appearance of close-range gunshot wounds involving tattooing and stippling patterns, as shown in Figure 2.12 a, b, and c (Di Maio, 1999 and Internet).

Contact distance wounds, Figure 2.12 a (Di Maio, 1999), produces very little stippling or gunshot residue around the entrance wound, however it does show a significant amount of soot deposition around the entrance wound and the muzzle pattern of the firearm (see Figures 2.12 a and b). These patterns only occur when the muzzle, or end of the barrel, of the firearm is pressed up against the target when the gun was fired. Near-contact wounds, shown in Figure 2.12 b (Di Maio, 1999), are a result when the end of the barrel is placed at a distance between contact and
10 mm away from the target. The type of wound pattern that is produced results in more stippling than is observed from a contact wound pattern. The tattooing around the entrance wound is broader from a near-contact wound than a contact wound pattern with no muzzle pattern apparent. An intermediate distance wound pattern is produced when the firearm is fired at a distance greater than 10 mm from the target, but still close enough for the smokeless powder to deposit on the target, as shown in Figure 2.12 c (Internet). This type of wound pattern has a smaller ring of tattooing around the entrance wound with a greater amount of gunshot residue distributed around the entrance wound. In this study, near-contact wounds were intended to be produced during the time the shooting experiments were performed, however based on observations made in Figures 2.5, 2.7, 2.9 and 2.10, and a comparison of the images in Figure 2.12 a, b, and c. The unexplained loss of powder and absence of soot produced in the porcine skin and white t-shirt gave the appearance of an intermediate gunshot wound. This observation could have been due to the variability in distance from where the firearm was fired at. Due to the pig skin being hung on an indoor target clip, there was no table or shelf that could be set up to verify the specific distance that the firearm needed to be fired at. Because the pig skin was hung in an indoor shooting range with other active shooters, a measuring tape was unable to be used to measure the distance from the firearm to the target. It was also concluded during this part of the study, that the tattooing and stippling patterns were similar for both the 9mm Luger round nose round and 9mm Luger hollow point bullets. Due to the safety precautions during the test firing, an actual measurement from the end of the barrel to the target was unable to be determined, however it was estimated to be 10 mm to 20 mm. Both target types (porcine skin and t-shirt) were shot from a similar distance so that the results between the two media are into comparable (Shepherd, et al, 2011).
Figures 2.12 a, b, c, and d: Images of contact wounds (left), near-contact wounds (middle), intermediate wounds (right), and gutter wound (bottom). (Di Maio, V. D. (1999). *Gunshot wounds: Practical aspects of firearms, ballistics, and forensic techniques*. Boca Raton, FL: CRC Press. And Internet).

The main ballistic features that were observed and compared throughout this section to distinguish the type of wound pattern made in the porcine skin and white t-shirt was the soot and stippling patterns. Powder tattooing, or stippling, is produced when the muzzle of the weapon is held away from the body at the time the gases and powders are discharged yet is sufficiently close enough that the powder grains expelled from the muzzle onto the skin. The tattooing
produced reddish-brown, punctate lesions surrounding the entrance of a gunshot wound. The small abrasions in the materials were due to the impact of the small fragments of foreign material released from the muzzle of the firearm. As shown in Figure 2.12 a, b, and c, there is both tattooing and soot present in the contact, near contact, and intermediate distance gunshot wounds produced on a material. Soot is carbon from vaporized metals produced from primer, bullet and cartridge casing and is released by the combustion of gunpowder that emerges from the muzzle of the firearm. As the range from the muzzle to target increases, the area of soot increases, however the density of the soot decreases. This illustration is shown in Figure 2.12 a, b, and c. The density (blackness) of the soot decreases as the distance between the firearm and the material increase.

In this section of the ballistic wounds study, porcine skin and a white t-shirt attached to a cardboard panel were used as tissue simulants for wound patterns that were produced in living human skin and tissue to evaluate distance of firing. The observations as well as the measurements from the entrance and exit wound diameters and presence/absence of tattooing and stippling powder around the entrance wounds. The amount of tattooing and stippling powder that was produced onto both the white t-shirt and porcine skin confirmed that the distance was approximately the same from the end of the handgun barrel to the target. This observation also confirmed that the gunshot wound patterns produced in the media were classified as intermediate gunshot wounds. The gunshot wounds produced were compared to literature (Di Maio, 1999) to validate these findings. To observe the stippling powder and tattooing produced from the fired bullets, the white t-shirt was an ideal media to use due to the color contrast, although it is recommended that both media are suitable for distance determination of fired handgun ammunition.
**Procedure for Different Media**

Different tissue simulants were fired at using 9 mm round nose bullets from a distance of 25 yards to compare the different wound patterns produced in different materials by the same type of ammunition. Ballistic gelatin and ballistic soap, two of the most common types of tissue simulants used for ballistic studies were fired into, as well as Permagel. Permagel is known as a more stable type of synthetic ballistic gelatin manufactured by Clear Ballistics, and is more translucent. The ballistic soap and ballistic gelatin were prepared prior to being fired into. The preparation of these materials are mentioned in Appendix I. Ballistic soap is prepared in a very similar way to ballistic gelatin (see Appendix I) with the exception that ballistic soap has a different ratio of water to gelatin, and the addition of glycerin soap base. The addition of the glycerin soap base resulted in a very different viscosity and strength of the material. The Permagel was purchased and shipped in a block formation ready to be fired into. Three 9 mm round nose bullets were fired into each of the three tissue simulants and the wound patterns produced were documented and measured.

In the first part of the ballistic studies, wound patterns were produced from fired .40 round nose and hollow point bullets in different types of potential simulants; ballistic gelatin, Permagel, ballistic soap, and regular soap. Permagel is a synthetic ballistic gelatin manufactured by Clear Ballistics. [https://www.clearballistics.com/](https://www.clearballistics.com/). The material used to produce the Permagel is a trade secret to the company, however, it is said to be stable, non-reactive to other materials or chemicals, and serves no health risks to the users. Permagel was made as a replacement for ordnance ballistic gelatin due to the instability of the ballistic gelatin and the requirements for specific storage conditions. Ballistic gelatin must be stored at 4°C and cannot be melted down
and reused. Ballistic gelatin is semi-transparent if made properly, however it still has an orange-yellow tint that may obscure results. Permagel is pre-made when ordered and comes in a large clear block, shown in Figure 2.13 c, rather than a powder melted in solution. The block of Permagel is thermally stable, as it was placed in freezing and melting conditions and the physical properties remained constant.

Figures 2.13 a -c: Wound patterns produced by fired 9 mm round nose bullets into ballistic soap (top), ballistic gelatin (bottom-left), and Permagel (bottom-right) from a distance of 25 yards.
After the potential tissue simulants were measured and documented, the ballistic soap, ballistic gelatin, and PermaGel were melted down using a heat source and stockpot. Once the materials were fully melted into a liquid form, the mixture was poured into a plastic mold container to harden. The PermaGel was left at room temperature to harden overnight and the ballistic gelatin and soap was placed in a cold storage room (4°C) and stored until they were fired at again. During the hardening process of the ballistic gelatin, the cold room malfunctioned and the temperature was increased over 4°C and the humidity rose inside the room. Because of this malfunction, the ballistic gelatin started to melt and became contaminated with mold. The growth of the bacteria made the ballistic gelatin unable to re-harden once the temperature was stabilized. Due to a lack of ballistic gelatin material and gelatin powder, only one distance was able to be recorded for comparison of the three types of ammunition and their hollow point compliments.

At a distance of 6 inches, 9 mm round nose and 9 mm hollow point, .40 Smith and Wesson (S & W) round nose and .40 hollow point, and .45 round nose Auto and .45 hollow point were each fired into blocks of ballistic gelatin for a comparison of the wound patterns that were produced. The 9 mm bullets were fired using the Glock 17 gen 4, which was used previously in the ballistic studies mentioned. The .40 S&W bullets were fired using a Glock 22 and the .45 automatic bullets were fired using a Glock 21. Three ballistic gelatin blocks were used in this ballistic study to compare each type of ammunition. Only two shots of each type of ammunition were fired into the ballistic gelatin blocks as to not risk wound cavity interference or tearing of the simulant. Once the wounds patterns were produced from each fired round, the wound patterns were observed and analyzed.
A number of .40 caliber round nose and hollow point bullets were fired into PermaGel to compare wound patterns produced by fired .40 bullets into PermaGel and ballistic gelatin. Two bullets were fired from each type of ammunition into the block of PermaGel and fired from a distance of 6 inches. The wound patterns that were produced were observed, analyzed and compared to the wound patterns produced in ballistic gelatin by the same type of fired rounds.

Ballistic soap and regular soap blocks were also fired at using .40 round nose and .40 hollow point rounds. The melting and re-hardening process of the ballistic soap was a success and was able to be used in more than once part of this ballistic study. The large block of regular
soap was made by melting very small slices of Dial soap and mixing with small amounts of water. Once the mixture was relatively homogeneous and completely melted, the mixture was placed in a plastic mold container and cooled to room temperature. The .40 round nose and .40 hollow point bullets were fired into both the ballistic soap and regular soap from a distance of 6 inches. The wound patterns that were produced were observed and analyzed, comparing the wound patterns to each other and to the ones produced from the ballistic gelatin and Permagel.

Figure 2.16: Ballistic soap block prepared for test firing.

Figure 2.17: Regular soap block prepared for test firing.
One of the firearm shooters that was helping to conduct this ballistic study inquired about the difference between ballistic soap and regular soap, and to observe how different the wound patterns would be. As a curiosity a large block of regular soap was prepared and the wound patterns were produced by fired .40 round nose and hollow point bullets, as shown in Figure 2.37 a and b. The preparation procedure of the regular soap block is described in Appendix I. Without the necessity of measuring the wound patterns that were produced, it was apparent that the regular soap had significantly different physical properties than the ballistic soap. The wound cavity produced in the regular soap block was significantly larger than that produced in the ballistic soap when the same type of ammunition was used and fired from the same distance (see Figure 2.37 a and b). Once the measurements of the wound patterns were documented, it was found that the entrance and exit wounds produced in the regular soap were at least ten times larger than those produced in the ballistic soap. If these types of media had similar physical properties, the wound patterns produced would be similar in appearance. An example of this would be the similarities of density properties between ballistic gelatin and ballistic soap.
Results of Different Media

Three different types of potential tissue simulants were fired at with 9 mm round nose ammo from the same distance to observe and compare the wound patterns produced. PermaGel is a clear and synthetic ballistic gelatin that is more stable than regular ballistic gelatin and is reusable and is formed from broken down animal collagen. When 9mm round nose bullets were fired into the PermaGel from a distance of 25 yards, the entrance wounds produced were circular in shape with little tearing of the material around the edges of the wounds. The fired bullets penetrated through the entire material and exited out the backside of the block. The fired bullets were never recovered from the indoor gun range. Due to the great distance between shooter and simulant, one fired round penetrated the PermaGel at a downward angle and exited through the bottom of the material. This may have prevented the measurement of the full penetration depth of the fired bullet and therefore the measurements may be inaccurate (Di Maio, 1999).

It was observed that the exit wounds were significantly smaller than the entrance wounds for the round nose bullets. The second 9 mm round nose bullet that was fired formed a wound pattern path that traveled from the right side of the Permagel block and exited out of the left side, about 14 cm from the end of the material. The fired bullet tore through the left side of the PermaGel, forming an elliptical pattern with a tail, showing the direction the bullet had traveled. This elliptical-shaped exit wound is shown in Figure 2.20. Similar to the second fired 9 mm round nose bullet, the third fired bullet also exited the PermaGel at an angle. The third fired bullet exited from the bottom of the Permagel block about 3 cm from the backside edge. The fired bullet tore an elliptical shape from the bottom of the simulant around the exit wound pattern. The measurements of the entrance wounds and exit wounds produced from the fired 9
mm round nose bullets in Permagel are summarized in Table 2.3. As shown in Figure 2.18, an abrasion collar was produced from a fired 9 mm round nose bullet penetrating the Permagel block from a distance of twenty-five yards. An abrasion collar occurs when the bullet rubs against the edges of the entrance hole and results in an indentation of the material. The abrasion ring is not due to the rotational movement of the bullet in air or due to the bullet burning the skin, rather it is due to the wiping of grease, burned powder and other debris from the barrel transferred to the bullet surface, which is then transferred to the skin at the site of penetration. (Di Maio, 1999).

Figure 2.18: An example of abrasion collar from 9 mm hollow point fired at approximately twenty-five yards into Permagel.
Figure 2.19: An example of two bullet tracks in Permagel. Two 9 mm round nose bullets traveling from left to right with bottom track exiting the gel at the end and upper track exiting the gel from the left side.

Figure 2.20: An elliptical-shaped exit wound produced in Permagel with a tail showing the direction the bullet traveled (left to right). This image shows an example of a tissue gutter wound.
Table 2.3: Measurements of fired 9mm round nose bullets fired from a distance of 25 yards into Permagel.

<table>
<thead>
<tr>
<th>9 mm round nose fired bullets fired into Permagel</th>
<th>Diameter of Entry Wound</th>
<th>Length of tearing around entrance wound</th>
<th>Length of wound penetration path in simulant</th>
<th>Diameter of Exit wound</th>
<th>Length of tearing around exit wound</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shot 1</td>
<td>2 mm</td>
<td>1 mm</td>
<td>39.6 cm</td>
<td>0.5 mm</td>
<td>0.5 mm</td>
</tr>
<tr>
<td>Shot 2</td>
<td>2.5 mm</td>
<td>0.5 mm</td>
<td>37.4 cm</td>
<td>0.6 mm</td>
<td>1 mm</td>
</tr>
<tr>
<td>Shot 3</td>
<td>3 mm</td>
<td>1 mm</td>
<td>24.4 cm</td>
<td>2 mm</td>
<td>3 mm</td>
</tr>
</tbody>
</table>

Ballistic soap was also fired at from a distance of 25 yards with 9mm round nose bullets. Unlike the entrance wound patterns formed from the PermaGel, the entrance wounds were circular in shape with little tearing around the edges. Because the ballistic soap was smaller in height than other potential tissue simulant blocks used, the shooter was not as accurate with the placement of the fired rounds, and the last round that was fired missed the ballistic soap block. The second shot that was fired into the ballistic soap grazed the top of the simulant, therefore penetrating the top of the simulant, and then exited the medium producing an 11.8 cm wound pattern. The area around the wound cavity formed by the second 9mm fired round was slightly raised and the fired bullet produced more tearing within the wound cavity than was formed when the 9mm fired round penetrated the PermaGel. Due to a difference in elasticity between PermaGel and ballistic soap, a larger entrance wound was observed, even though the same ammunition was used for both types of simulants. The third fired round missed the simulant and therefore no wound pattern was made. As shown in Figure 2.20 in Permagel, and Figure 2.21 a and b in ballistic soap, there was evidence of gutter and grazing wounds produced from the fired 9 mm round nose bullets. Grazing wounds are produced when the bullet strikes the material at the shallow angle, producing an elongated area of abrasion without tearing of the material. If the grazing wound extends downs through the subcutaneous tissue, the skin is torn or lacerated by...
the bullet and is known as a gutter wound. An illustration of a gutter wound is shown in Figure 2.12 d (Di Maio, 1999).

Figure 2.21 a and b: An example of grazing, gutter wound in ballistic soap from 9 mm round nose bullet fired from approximately twenty-five yards.

Table 2.4: Measurements of fired 9mm round nose bullets fired from a distance of 25 yards into Ballistic Soap.

<table>
<thead>
<tr>
<th>9 mm round nose fired bullets fired into Ballistic Soap</th>
<th>Diameter of Entry Wound</th>
<th>Length of wound penetration path in simulant</th>
<th>Diameter of Exit wound</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shot 1</td>
<td>1.0 cm</td>
<td>39.1 cm</td>
<td>W: 1.5 mm</td>
</tr>
<tr>
<td>Shot 2</td>
<td>1.5 cm</td>
<td>11.8 cm</td>
<td>1.5 cm</td>
</tr>
<tr>
<td>Shot 3</td>
<td>-----</td>
<td>-------</td>
<td>----------</td>
</tr>
</tbody>
</table>

Like the experiments performed on PermaGel and ballistic soap, three 9 mm round nose bullets were fired into ballistic gelatin from a distance of 25 yards. All three fired bullets penetrated through the entire thickness of the ballistic gelatin and exited out the opposite side. The fired bullets penetrated the gel and were never recovered, like the bullets that were fired into the PermaGel and ballistic soap. The first fired round produced an entrance wound that appeared more like a tear in the material than a bullet hole. Due to the force of the bullet traveling through the ballistic gelatin, there was tearing around the entire wound cavity. This observation is shown in Figure 2.22. The tearing on the top of and around the wound cavity formed in a swirl-like
pattern flowering around the wound. The temperature of the storage conditions decreased significantly after the tissue simulant blocks were shot into, and as a result, the ballistic gelatin and ballistic soap froze and re-thawed. The freezing of the ballistic gelatin resulted in many tears and cracks around the sides of the block. The freezing of the media was not intentional and was due to a quick swing in temperature in the storage container. These cracks and tears affected the entrance and exit wounds before the wounds were documented and therefore it was unknown if the tears were caused by the force of the bullet penetrating the simulants or if they occurred when the block froze. Unfortunately, the photographs of the gelatin taken before it froze did not show detail patterns of the gunshot wound patterns. The entrance wounds that were produced from the penetrating fired 9 mm bullets appeared as small tears and indentations instead of bullet holes. Like the exit wounds in PermaGel and ballistic soap, the exit wounds were larger in diameter than those of the entrance wounds. One difference that was observed was there was no tearing around the exit wounds in the ballistic gelatin.
Figure 2.22: Entrance wound produced in ballistic gelatin from a fired 9mm round nosed bullet at a distance of twenty-five yards.

Table 2.5: Measurements of fired 9mm round nose bullets fired from a distance of 25 yards into Ballistic Gelatin.

<table>
<thead>
<tr>
<th>9 mm round nose bullets fired into Ballistic Gelatin</th>
<th>Diameter of Entry Wound</th>
<th>Length of tearing around entrance wound</th>
<th>Diameter of Exit wound</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shot 1</td>
<td>W: 5 mm</td>
<td>1.7 cm</td>
<td>2 mm</td>
</tr>
<tr>
<td>Shot 2</td>
<td>9 mm</td>
<td>-----------</td>
<td>2 mm</td>
</tr>
<tr>
<td>Shot 3</td>
<td>-----------</td>
<td>-----------</td>
<td>-----------</td>
</tr>
</tbody>
</table>
After melting the blocks of ballistic gelatin, ballistic soap and Permagel, it was determined that the ballistic gelatin was unable to be melted and reused. It was found in the literature that ballistic gelatin is not re-usable, which was one of the disadvantages to using this type of material (Jussila, 2004). Permagel could be successfully melted and reused for other ballistic studies. It was observed that the PermaGel was not as transparent as before the block was melted down, shown in Figure 2.24 a and b. The ballistic soap was also successfully melted down and hardened in order to be reused.

Figure 2.23: A close-up of a temporal cavity and bullet track in ballistic gelatin produced from a fired 9 mm round nose bullet that has transverse one ballistic gelatin block 18 inches long and entered a second block of ballistic gelatin.

Figure 2.24 a and b: Permagel block appearance from supplier and then the appearance of Permagel block after being melted down and then hardened for reuse.
In the second part of the shooting experiments, the different types of ammunition were fired into ballistic gelatin from a distance of 6 inches. Three 9 mm round nose bullets were fired into the left side of the gelatin blocks and three 9 mm hollow point bullets were fired into right side of the gelatin blocks. Only three round nose and hollow point bullets were fired into the gelatin block so that the wound patterns and cavities would not interfere with one another. The entrance wound of the first 9 mm round nose round produced an indentation in the top left corner of the block with tearing of the material around the entrance wound. When the fired bullet penetrated the ballistic gelatin, a bullet hole and wound cavity was produced. When the wound compressed back to its original position, the wound appeared to be closed. All three fired bullets from the 9 mm round nose bullets produced very similar entrance wounds and penetrated through the entire block of ballistic gelatin. The exit wounds produced from the fired bullets were smaller in diameter than the corresponding entrance wounds and appeared to have little
tearing around the exit wounds. The detailed measurements of the entrance and exit wounds from the 9mm round nose bullets are shown in Table 2.6.

On the right side of the same block of ballistic gelatin, three fired 9mm hollow point bullets were fired from the same firearm as used for the 9mm round nose rounds. In comparison to the wound patterns produced from a fired 9mm round nose round, 9mm hollow point bullets produced an entrance wound with large amounts of tearing around the edges, shown in Figure 2.32 a and b. The force of the fired bullet penetrating the block of ballistic gelatin resulted in significant tearing and pieces of ballistic gelatin exploding from its original position near the wound pattern. The larger surface area of the 9mm hollow point bullets resulted in a shorter penetration depth and the fired bullet was able to be recovered from the block of ballistic gelatin (Figure 2.26).

Because the 9mm hollow bullets did not go all the way through the gelatin block, there was no exit wound to measure nor any tearing around the wound pattern. At least one bullet fragment from each 9mm hollow point fired bullet that was recovered in the ballistic gelatin, and in most cases the fragment was found within 6 mm of where the fired bullet was found. Since there was bullet fragments there should have been additional wound tracks, however there was no additional tearing or wound cavities observed from the detached bullet fragments. Fragmentation can cause additional damage if the fragments create additional wound tracks.
Figure 2.26: Fired 9mm Luger hollow point bullet recovered from inside the ballistic gelatin.

Figure 2.27 a and b: Example of the terminal bullet track expanded and fragmented bullet (9 mm hollow point) in ballistic gelatin.

Figure 2.28: Example of exit wounds in ballistic gelatin, the one exit wound on the left of the image was produced from a 9 mm hollow point bullet and the three right exit wounds were produced from 9 mm round nose bullets.
The same procedure was performed with .40 S&W (Smith & Wesson) and .40 HP LEI (Hollow Point Law Enforcement Issued) bullets fired into ballistic gelatin from a distance of six inches, as with the 9 mm Luger bullets that were fired into ballistic gelatin. Three .40 S & W round nose bullets were fired into the left side of the ballistic gelatin block and three .40 HP LEI bullets were fired into the right side of the ballistic gelatin block. The entrance wounds produced from the fired .40 round-nose bullets were larger in diameter than those produced from a 9 mm round nose round when fired into the same type of material. Significant tearing around the entrance wound was observed around each of the entrance wounds produced from the fired .40 round-nose rounds, along with evidence of unburnt gunshot powder. Exit wounds were produced from all three fired .40 round nose rounds, meaning the fired bullets penetrated through the entire block of ballistic gelatin. The exit wounds were smaller in diameter than the corresponding entrance wounds with little to no tearing present. Due to the slight downward angle of all three wound cavities, the third fired round-nose round tore through the bottom of the ballistic gelatin block approximately 6 cm from the back-edge of the block. In comparison to the .40 round-nose rounds, three .40 hollow point bullets were fired into the right side of the block of ballistic gelatin fired from a distance of 6 inches. The entrance wounds produced from the fired hollow point bullets were larger in diameter with longer tearing patterns around the edges. The fired hollow point bullets did not penetrate through the entire gelatin block and the fired bullet fragmented inside of the ballistic gelatin. The .40 hollow point bullets produced shorter wound cavities than those produced by 9mm hollow point rounds. This is most likely due to the larger surface area of the .40 caliber bullet than of the 9mm bullet, resulting in a greater energy loss due to a larger surface area between the fired round and the ballistic gelatin material, resulting in a shorter penetration depth. The pedals on the fired .40 hollow point bullets were thicker than those
of the fired 9 mm hollow point bullet, forming a 5-pointed star instead of bullet fragments found within the wound cavity of the ballistic gelatin. The ballistic gelatin block was cut along the path of the wound cavity and it was measured that the diameter of the wound cavities for both .40 round nose and .40 hollow point bullets were consistent with one another, 2 mm in diameter. A photograph of this is shown in Figure 2.34. The only difference between the wound cavities was the amount of expansion around the wound cavity was larger from the expanded hollow point bullet. The expansion of the wound track may be due to tumbling bullets or expanding hollow point bullets.

Figure 2.29: Sample wound tracks produced through ballistic gelatin from fired .40 caliber hollow point bullets at a distance of six inches.
Figure 2.30: Three shots through ballistic gelatin. With bullets traveling from left to right of the image illustrating expansion and bullet path terminated with expanded bullets in the gelatin block (top two tracks) and bullet completely exiting at the bottom bullet track.

Figure 2.31: An example of an expanded .40 caliber bullet in ballistic gelatin.
Based on the patterns observed in Table 2.6, it was hypothesized that a wound pattern produced by .45 auto round nose and hollow point bullets would produce larger diameter entrance wounds and longer amount of expansion around the entrance wound in ballistic gelatin based on the findings in this study. The chemical structure of the gelatin was compromised and was unable to harden and stiffen throughout the entire block. Three .45 auto round nose bullets were fired into the left side of the ballistic gelatin from a distance of 6 inches. The three fired bullets penetrated through the entire gelatin block and the fired bullets were never recovered. The entrance wound produced from the first fired .45 round nose round was small in diameter with no tearing present along the outside of the entrance wound. The second .45 round nose round was fired at an angle that caused the bullet to interfere with the wound cavity produced by the first fired round. This resulted in the second bullet to exit out of the same exit wound produced by the first round. The third fired .45 round nose round penetrated the ballistic gelatin block and moved in a downward angle, eventually exiting through the bottom of the ballistic gelatin and through the table that was holding the materials off the ground. Based on these observations, accurate exit wound measurements could not be determined. Three .45 hollow point bullets were fired into the right side of the block of ballistic gelatin from a distance of 6 inches. These fired
hollow point bullets caused the ballistic gelatin block to split in half because the middle of the ballistic gelatin was liquid gelatinous. Fortunately, the splitting of the gelatin block did not contaminate the wound patterns produced from either the .45 round nose or .45 hollow point rounds. This study involving the comparison of the wound patterns from .45 round nose bullets and .45 hollow point bullets in ballistic gelatin will need to be repeated in order to reproduce more accurate results in future research. The exit wounds produced from the fired .45 hollow point bullets were measured and summarized in Table 2.6. Similar to the wound patterns produced by fired .45 round nose bullets, there was no tearing present around the entrance or exit wounds. Stellate tearing can be exhibited in human skin, usually from contact shots, as shown in Figure 2.12 d. The extent of tearing is not particularly diagnostic as it depends on the underlying bony structure in a human body, bullet caliber, muzzle velocity, etc. The tears radiate out in a star-shaped hence it is described in the literature as stellate tearing.

Figure 2.33: Entrance wounds produced from fired .40 round nose (left) and hollow point (right) bullets into ballistic gelatin from a distance of six inches illustrating stellate tearing (right side).
Figure 2.34: Ballistic gelatin block cut along the wound cavities produced by fired .40 hollow point bullets from a distance of six inches.

There are two bullet paths shown in Figure 2.34. The arrows shown in this figure correlate to the direction the bullet traveled to produce each path.

Table 2.6: Detailed wound pattern measurements of various caliber ammunition in ballistic gelatin fired from a distance of six inches.

<table>
<thead>
<tr>
<th></th>
<th>9 mm Round nose</th>
<th>9 mm hollow point</th>
<th>.40 round nose</th>
<th>.40 hollow point</th>
<th>.45 round nose</th>
<th>.45 hollow point</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter of entrance wound</td>
<td>S 1: 9 mm indentation</td>
<td>S 1: 6 mm S 2: 6 mm S 3: 5 mm</td>
<td>S 1: 4 mm S 2: 4 mm S 3: 3.5 mm</td>
<td>S 1: 7.5 mm S 2: 8 mm S 3: 7.5 mm</td>
<td>S 1: 3 mm S 2: 2 mm S 3: 4 mm</td>
<td>S 1: 5 mm S 2: 5 mm S 3: 4 mm</td>
</tr>
<tr>
<td>Length of tearing around entrance wound</td>
<td>5 mm</td>
<td>9 mm- 21 mm</td>
<td>7.5 mm</td>
<td>3 mm- 15 mm</td>
<td>No tearing</td>
<td>No tearing</td>
</tr>
<tr>
<td>Length of penetration depth</td>
<td>39.2 cm</td>
<td>S 1: 37.1 cm S 2: 35.7 cm S 3: 36.0 cm</td>
<td>29.2 cm</td>
<td>S 1: 28.8 cm S 2: 29.2 cm S 3: 31.1 cm</td>
<td>38.6 cm</td>
<td>38.6 cm</td>
</tr>
<tr>
<td>Diameter of exit wound</td>
<td>S 1: 2 mm S 2: 4 mm S 3: 3 mm</td>
<td>No exit wounds</td>
<td>S 1: 2 mm S 2: 2 mm S 3: 4 mm</td>
<td>No exit wound</td>
<td>No exit wound</td>
<td>S 1: 5 mm S 2: 5 mm S 3: No exit wound</td>
</tr>
</tbody>
</table>

S: shot, S 1: 9 mm indentation= Shot one: 9 mm indentation
It was expected that the exit wounds would be larger in diameter than the entry wounds. The trend observed in Table 2.6 is consistent if there was no tumbling or bullet fragmentation observed from the wound track, however both tumbling and bullet fragmentation were observed in this study. Since this was a consistent observation, throughout this study, it was determined that this was another criterion where the media does not match up with living tissue, generally.

The different simulants (ballistic gelatin, Permagel, ballistic soap, and regular soap) were fired into, producing wound patterns from .40 Smith and Wesson round nose and hollow point fired rounds. In Permagel, three fired .40 Smith and Wesson round nose bullets were shot into the simulant on the left side of block, and three fired .40 Smith and Wesson hollow point bullets were shot into the simulant on the right side of the block. Like the 9mm fired round being shot into the Permagel in the first part of the study, there was no observed tearing around the entrance or exit wounds. It was also observed that the entrance wounds for both the round nose and hollow point bullets were circular in shape. Around each of the entrance wound patterns, there was a ring of singed material (Permagel) from the fired bullets penetrating through the material, also known as an abrasion collar. This pattern is a good indicator of an entrance wound vs. an exit wound. The block of Permagel is light in color and can show the gunshot residue around each of the entrance wounds. All six fired bullets penetrated through the entire Permagel block. The measurements values of the wound patterns are shown in Table 2.7. The measurements of the wound patterns produced in the PermaGel block were compared to those produced in the ballistic gelatin block.
Table 2.7: Measurements of wound patterns produced from fired .40 Smith and Wesson round nose and hollow point bullets into Permagel from a distance of six inches.

<table>
<thead>
<tr>
<th>.40 S&amp;W standard fired rounds in Permagel</th>
<th>Diameter of Entry Wound</th>
<th>Width of Abrasion collar around entrance wound</th>
<th>Length of wound penetration path in simulant</th>
<th>Diameter of Exit wound</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shot 1</td>
<td>4 mm</td>
<td>2 mm</td>
<td>38.9 cm</td>
<td>1 mm</td>
</tr>
<tr>
<td>Shot 2</td>
<td>3.5 mm</td>
<td>1 mm</td>
<td>38.9 cm</td>
<td>1 mm</td>
</tr>
<tr>
<td>Shot 3</td>
<td>4.5 mm</td>
<td>1 mm</td>
<td>38.9 cm</td>
<td>1 mm</td>
</tr>
<tr>
<td>.40 S&amp;W hollow-point fired rounds in Permagel</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shot 1</td>
<td>5.0 mm</td>
<td>-----</td>
<td>38.9 cm</td>
<td>1 mm</td>
</tr>
<tr>
<td>Shot 2</td>
<td>5.5 mm</td>
<td>-----</td>
<td>38.9 cm</td>
<td>1 mm</td>
</tr>
<tr>
<td>Shot 3</td>
<td>5.5 mm</td>
<td>-----</td>
<td>38.9 cm</td>
<td>1 mm</td>
</tr>
</tbody>
</table>

Figure 2.35: Entrance shots from fired .40 Smith and Wesson round nose (left) and hollow point (right) bullets into Permagel, shot from a distance of six inches away.

Ballistic soap was shot at from a distance of six inches and wound patterns were produced from fired .40 Smith and Wesson round nose and hollow point rounds. Three .40 Smith and Wesson round nose bullets were fired on the left side of the ballistic soap block and three .40 Smith and Wesson hollow point bullets were fired on the right side of the ballistic soap block. As
shown in Figure 2.36 and Figure 2.37, all six entrance shots were relatively irregular in shape and had a significant amount of tearing around the edges. Because the block of ballistic soap was light in color, gunshot residue was observed around the entrance wounds for both the fired round nose bullets and hollow point rounds. Around the entrance wounds there was a ring of singed material resulting from the heat and friction of the bullet moving forward, which simulates an abrasion collar that is often seen in entry wounds in human tissue. This observation was similar to the entrance wounds produced in the Permagel. One difference that was observed was the singed ballistic soap around the entrance wounds were deeper and wider than the wounds produced in Permagel, see Figure 2.18. The exit wounds produced in the ballistic soap were irregular in shape and had tearing around the edges. The fired .40 Smith and Wesson round nose bullets produced an exit wound where a ring of ballistic soap extended outward of the block. As observed in the measurements in Table 2.8, the penetration depth of the .40 hollow point bullets was shorter than the penetration depths of the round nose rounds.
Table 2.8: Measurements of wound patterns produced from fired .40 Smith and Wesson round nose and hollow point bullets into ballistic soap from a distance of six inches.

<table>
<thead>
<tr>
<th>.40 S&amp;W round nose fired bullets in Ballistic Soap</th>
<th>Diameter of Entry Wound</th>
<th>Length of tearing around entrance wound</th>
<th>Length of wound penetration path in simulant</th>
<th>Diameter of Exit wound</th>
<th>Length of tearing around exit wound</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shot 1</td>
<td>2 mm indentation</td>
<td>No tearing</td>
<td>38.9 cm</td>
<td>4 mm</td>
<td>2.0 cm</td>
</tr>
<tr>
<td>Shot 2</td>
<td>2 mm indentation</td>
<td>No tearing</td>
<td>38.9 cm</td>
<td>No exit wound</td>
<td>2.6 cm</td>
</tr>
<tr>
<td>Shot 3</td>
<td>1.5 mm indentation</td>
<td>No tearing</td>
<td>38.9 cm</td>
<td>4.3 mm</td>
<td>4.1 cm</td>
</tr>
<tr>
<td>.40 S&amp;W hollow point fired bullets in Ballistic Soap</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shot 1</td>
<td>6 mm</td>
<td>2 mm</td>
<td>38.9 cm</td>
<td>4 mm</td>
<td>4.9 cm</td>
</tr>
<tr>
<td>Shot 2</td>
<td>7 mm</td>
<td>2 mm</td>
<td>28.0 cm</td>
<td>No exit wound</td>
<td>2.8 cm</td>
</tr>
<tr>
<td>Shot 3</td>
<td>6 mm</td>
<td>5 mm</td>
<td>28.0 cm</td>
<td>No Exit wound</td>
<td>2.8 cm</td>
</tr>
</tbody>
</table>

Figure 2.36: Entrance shots from fired .40 Smith and Wesson round nose (left) and hollow point (right) bullets into ballistic soap, shot from a distance of six inches away.
Figure 3.37: Closer view of entry wounds, tattooing, and soot in ballistic soap from approximately six inches using 9 mm hollow point ammunition.

A block of regular soap was fired at using .40 Smith and Wesson round nose and hollow point bullets to compare the wounds produced in ballistic soap to regular soap. As performed with the ballistic gelatin, PermaGel, and ballistic soap, three shots of round nose and hollow point bullets were meant to be fired into the regular soap, however the wound patterns that were produced were so large that only one round nose and one hollow point bullets could be fired into the material. The entrance wound produced from the round nose wound was irregular in shape and showed very little to no tearing around the edge. The entrance wound produced from the .40 Smith and Wesson hollow point was more circular in shape with little to no tearing around the edge. The exit wound produced from the .40 Smith and Wesson round nose round was more circular in shape than its corresponding entrance wound. The exit wound produced from the .40 Smith and Wesson hollow point round was found on the bottom of the block and resulted in tearing of the regular soap, extending outward from the exit wound.
Table 2.9: Measurements of wound patterns produced from fired .40 Smith and Wesson round nose and hollow point bullets into regular soap from a distance of six inches.

<table>
<thead>
<tr>
<th></th>
<th>Diameter of entrance wound</th>
<th>Length of Penetration Depth</th>
<th>Diameter of exit wounds</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>.40 S&amp;W standard rounds</strong></td>
<td>3.1 cm</td>
<td>34.8 cm</td>
<td>4.1 cm</td>
</tr>
<tr>
<td><strong>.40 S&amp;W hollow-point rounds</strong></td>
<td>2.1 cm</td>
<td>34.8 cm</td>
<td>1.8 cm</td>
</tr>
</tbody>
</table>

Figure 2.38 a and b: Entrance wounds from fired .40 Smith and Wesson round nose bullet on the left side of the block and hollow point bullet on the right side of the block into regular soap, shot from a distance of six inches away. The right photo shows the inside of the wound cavity formed from the fired hollow point bullet.
**Discussion of different media**

A 9 mm Luger round nose and hollow point bullets were fired into ballistic gelatin, ballistic soap, and Permagel from a distance of 25 yards away. The wound patterns that were produced from these fired bullets were documented and measured, shown in Tables 2.2-Tables 2.6. There were different types of wound patterns that were produced in the media, such as grazing or gutter wounds, stellate tearing, and abrasion collars, illustrated in Figure 2.39 a. Other than these specific types of wound patterns that were produced in the media, specific types of wound patterns were produced from the different caliber ammunition. In Permagel, there was very little to no tearing around the entrance/exit wounds as well as inside the wound channel. The three wound patterns that were produced from the fired 9 mm round nose bullets and fired from a distance of 25 yards were similar in measurements, as shown in Table 2.3. The diameter of the entrance wounds that were produced, as well as the length of tearing around the entrance wounds were similar in measurements, and therefore support the hypothesis that wound patterns can be accurately reproduced.

One of the fired bullets only grazed the top of the ballistic soap, shown in Figure 2.22 a and b, however shows how the media reacted to the production of a graze or gutter wound. The other two wound patterns that were produced in ballistic soap consisted of entrance wounds and exit wound diameter values that were similar, as shown in Table 2.4. Both of the fired 9 mm round nose bullets that produced wound channels penetrated through the entire ballistic soap block, and therefore the kinetic energy within the bullet was not completely lost from wound formation.
Because all the fired 9 mm round nose bullets penetrated through Permagel and ballistic soap, two ballistic gelatin blocks were placed together and fired at from a distance of 25 yards to observe if an extra block of ballistic gelatin would stop the bullet. Two 9 mm round nose bullets were fired into the media and penetrated through the entire 78.2 cm ballistic gelatin blocks. One fired bullet completely missed the ballistic gelatin block due to the long distance between the firearm and target. There was significant amount of cavity expansion along the wound channel, as shown in Figure 2.24 showing the temporal cavity that was formed from the projected bullet. The wound patterns that were produced in the ballistic gelatin were measured and documented, shown in Table 2.5. there was more variability in the measurements from the wound patterns that were produced, however the diameter of the exit wounds was similar in value.

Distant gunshot wounds are defined when the muzzle of the firearm is sufficiently far from the target and there is no tattooing nor soot observed around the entrance wounds that are produced. Distant wounds are created when the firearm is 60 cm (24 inches) or greater from the target.

One of the major types of wound patterns that are produced from distant gunshot wounds are abrasion collars. This wound pattern, along with the lack of soot and tattooing suggests a distant range of fire (Di Maio, 1999). A comparison of the wound patterns produced in Permagel, ballistic soap, and ballistic gelatin with the entrance wounds produced in living tissue suggests that the wound patterns that were produced from the 9 mm round nose bullets from a distance of 25 yards away were distant gunshot wounds. This comparison can be illustrated from Figures 2.19, 2.33, 2.35, and 2.37 with Figure 2.39 a and b (Internet).
In the second part of this study, the media were fired at with different caliber ammunition from a distance of 6 inches. Wound patterns were produced in ballistic gelatin from fired 9 mm Luger round nose and hollow point bullets, .40 caliber Smith and Wesson round nose and hollow point bullets, and .45 caliber auto round nose and hollow point bullets and were measured and documented. The fired 9 mm hollow point bullets mushroomed or fragmented once they penetrated the ballistic gelatin block and two of the three hollow point bullets terminated in the ballistic gelatin block. All the kinetic energy from the bullet was lost into the wound formation as evidenced by termination within the gel.

All three 9 mm round nose bullets that were fired into the block of ballistic gelatin and penetrated through the entire media block. The .40 and .45 caliber ammunition were also fired into ballistic gelatin from a distance of 6 inches away and the wound patterns were measured and documented, shown in Table 2.6. The wound patterns that were produced by the fired 9 mm round nose and hollow point bullets in ballistic gelatin, were similar in appearance to those produced in the .40 Smith and Wesson round nose and hollow point bullets, resulting in no exit wounds from the fired hollow point bullets and present exit wounds from the fired round nose.
bullets. It was hypothesized that the .45 caliber round nose and hollow point bullets would produce similar wound patterns to the 9mm and .45 type ammunition, however as observed in Table 2.6, this was not observed. There is no consistent trend in the measurements that were obtained between the wound patterns produced in the 9mm Luger, .40 Smith & Wesson, and .45 auto caliber ammunition. Based on the measurement values obtained from the various wound patterns produced in the ballistic gelatin from the different caliber ammunition, it was observed that the hollow point bullets produced larger entrance wounds than corresponding round nose bullets of the same caliber.

The literature (Di Maio, 1999), suggests that the larger the caliber of ammunition fired, the larger the entrance wound. Based on the measurements taken from this part of the study, shown in Table 2.6, this relationship was not confirmed in ballistic gelatin because two wound patterns that were produced from the fired .45 automatic round nose bullets exited out of the same exit wound and therefore an accurate exit wound measurement was unable to be determined.

The literature also indicates that the penetration depths of the hollow points bullets are shorter than the fired round nose round due to the wider surface area resulting from the expanding hollow point bullet (Di Maio, 1999). When the hollow point bullet is fired, the sides of the bullet around the hollow nose are pushed back and outward due to the excessive force and friction being applied to the projectile. The sides form petals, which may result into bullet fragments if they are detached from the bullet. See Figure 2.32 a and b for an example of a fully expanded bullet. The additional surface area on the bullet causes more friction against the material and greater energy loss, resulting in more stopping power of the fired hollow point round (Shepherd, 2011).
In this study, the wound patterns of fired .40 hollow point bullets and fired .40 hollow point law enforcement issue bullets were compared in ballistic gelatin at the same firing distance. The literature indicates that there was no difference between these two types of ammunition, expect that law enforcement issued ammunition was not sold in stores and could only be purchased online (Anonymous, 2018). The wound patterns produced by these two types of ammunition were compared in ballistic gelatin. Based on the measurements shown in Table 2.6, it was found that the measurements were consistent with each other and that there were no major differences between the law enforcement issued bullets and the regular hollow point rounds. The entrance and exit wounds diameter results from this part of the study validate the information found in literature (Shepherd, et al, 2011).

Ballistic soap was used as a potential tissue simulant, in which .40 Smith and Wesson round nose and hollow point bullets were fired into from a distance of 6 inches, producing wound patterns that were measured and documented. The wound channels produced by the fired bullets were observed by cutting along the wound pattern. Penetration of this material by the fired bullets caused plastic-like deformations in the wound channels. Materials exhibiting plastic deformation display a change in shape that is not reversible. The changes that are made to the material are permanent and when the stress of changing a material is removed, the material will not go back to its original shape (Callister, 2004). These wound channels mimic the maximum amount of the temporal cavity that is produced from the force of the bullet traveling as a projectile through the material. The temporal cavity produced in ballistic soap is shown in Figure 2.40 a (Internet), showing the maximum extent of tissue that would be effected from bullet penetration, versus the permanent cavity produced in ballistic gelatin as shown in Figure 2.40 b (Internet). The temporary cavity, or temporal cavity, only exists briefly after the bullet passes
through human tissue, however it will still cause tissue damage without a wound cavity being present in that area. The fired bullet transfers energy from itself to the medium, which produces high pressure and velocity in the medium around the path of the bullet, causing a hollow space behind the bullet, due to a vacuum. The temporary cavity that is produced reaches a maximum diameter at a specific point as the cavity fills with air from the entry wound. In most materials or tissue simulants, the cavity collapses after a few milliseconds due to the bullet’s energy being converted into elastic energy of the material, leaving only the permanent cavity left by the bullet itself. With the addition of the glycerin molecules, the triple helix structures of the liquid gelatin become more complex, leaving very little room for the atoms or molecules to move around. This results in the material having fewer elastic properties, becoming more plastic-like (Shepherd, et al, 2011).

Figure 2.40 a and b: Image of a temporal wound cavity produced in ballistic soap (left) verses permanent wound cavity produced in ballistic gelatin (right). (Google Images).
Three .40 Smith and Wesson round nose and hollow point bullets were each fired from a distance of 6 inches away in Permagel and the measurements were summarized in Table 2.8. The measurements of the wound patterns produced by the fired .40 round nose bullets were very similar in value, both the entrance and exit wounds. The same fact also holds for the measurements of the wound patterns produced from the .40 hollow point bullets. This observation supports that the wound patterns can be reproducible. Both types of .40 caliber ammunition fired into the Permagel completely penetrated through the media block, indicating that the kinetic energy from the bullet was not totally lost to wound formation. As shown in Figure 2.35, there is tattooing and soot around the entrance wounds produced by both the .40 Smith & Wesson round nose and hollow point bullets. The tattooing and soot patterns on the Permagel are similar in appearance to the intermediate-ranged gunshot wounds as shown in the first section of Chapter Two, Figure 2.12 c. This observation suggests that the wounds patterns were produced from a firearm that was fired from a distance greater than 10 mm but less than 60 cm.
The media throughout this study was used to evaluate specific variables and properties of gunshot wounds produced from various handgun ammunition. These properties and variables include bullet path, energy loss, the extent of temporal cavity formation which reflect bullet energy loss and stopping power, and how bullet deformation occurs and distance determination in different media. When a bullet strikes human tissue, it produces injuries by two mechanisms, direct crushing and shredding a wound track that is similar in diameter to the bullet, and the temporal cavity produced. The severity of the wound is directly related to the amount of kinetic energy that is lost in the tissue, however not the total energy that is possessed by the bullet. Kinetic energy is the type of energy that is possessed when an object is in motion. If the bullet penetrates the material but does not exit, then all of the kinetic energy was utilized in wound formation. In comparison, if the bullet penetrates through the entire media, only part of the kinetic energy was lost in wound formation and therefore is less severe than the wound produced from a non-exit wound gunshot. The temporal cavity formation reflects the bullet energy loss and stopping power. The formation of a temporal cavity involves a series of small pulsations and contractions before it disappears, resulting in the permanent cavity. The locations, size, and the shape of the temporal cavity in live human tissue depends on the amount of kinetic energy lost by the bullet in its path and how rapidly the energy is lost. The maximum diameter of the cavity occurs at the point at which the maximum rate of kinetic energy is lost occurs. Hollow point ammunition was designed to mushroom or fragment when penetrated in living tissue, which causes penetration rather than perforation wounds with a complete loss of kinetic energy. All of these properties and variables studied throughout this study are important for observing wound patterns that are produced in the different media. (Di Maio, 1999).
Table 2.10: Summary of findings for the different media and how they compare to human tissue.

<table>
<thead>
<tr>
<th>Entry wound size</th>
<th>Exit wound size</th>
<th>Depth of Penetration</th>
<th>Cavity diameter</th>
<th>Fragmentation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ballistic Gelatin</strong></td>
<td>7.5 mm</td>
<td>N/A</td>
<td>29.2 cm</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Ballistic Soap</strong></td>
<td>6 mm</td>
<td>N/A</td>
<td>28.0 cm</td>
<td>2.8 cm</td>
</tr>
<tr>
<td><strong>Permagel</strong></td>
<td>5.5 mm</td>
<td>1.0 mm</td>
<td>&lt; 38.9 cm</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Regular Soap</strong></td>
<td>2.1 cm</td>
<td>1.8 cm</td>
<td>&lt; 34.8 cm</td>
<td>2.0 cm</td>
</tr>
</tbody>
</table>

Table 2.10 illustrates a summary of the information gathered from this section of the study from the hollow point ammunition fired into the various tissue simulants. Based on the information gathered, it is recommended that the better type of simulant to use for the reconstruction of gunshot wounds produced by fired handgun ammunition is ballistic gelatin or ballistic soap. These tissue simulants closely compare to the variables that would be observed in human tissue. Bullet fragmentation was observed in the ballistic gelatin, which is important in explaining the excess damage that occurs in human tissue when hollow point ammunition is fired.
Chapter Three: Bite Mark Wound Patterns

**Introduction**

A bite mark is defined as a mark caused by the teeth and/or other mouth parts of an animal. The nature of the contact between the mouthparts and the bitten material can have a significant influence on the bite mark pattern. This type of wound produced has potential individual characteristics of the biter. Patterns such as dental arches, individual teeth, the size of the jaw, and significant gaps between teeth analyzed and compared to known dental records and molds.

Wound patterns produced by bite marks can be a combination of several types of wounds; consisting of contusions and abrasions in the human skin. These types of wounds depend on the severity of the wound and how it was inflicted. One of the main difficulties in the analysis and reconstruction of bite marks in a forensic setting is the analysis of the wound in human skin. The distortion of the bite mark in the human skin, as well as how the biter inflicted the wound, may modify the appearance of the wound pattern. The degree of movement between the teeth and the bitten tissue range from nil in static bite marks to extreme tooth scrape marks. An example of these bite mark distortions can be seen in Figure 3.1 a, b, and c (Sheasby & MacDonald, 2001). These bite mark impressions are produced by the same dental molds however distorted in various ways to appear like different types of bite mark wound patterns. The number of bites produced in the same area, as well as how wide the assailant’s mouth was open when the bite occurred are different types of distortions that can be produced in the wound pattern (Sheasby, et al, 2001). Clothing also has an effect on the bite mark wound pattern produced. Clothing can act as cushion
for the affected tissue area which may lessen the appearance of the bite mark wound pattern or alter it. The fibers or designs on the clothing could affect the wound pattern and the design may be seen within the wound. If the bite mark patterns are extremely modified, it will no longer appear as a mirror image of the actual teeth impressions of the assailant as an accurate representation of the true teeth impressions of the assailant (Avon & Wood, 2005).

Figure 3.1 a, b, c: Bite mark wound patterns produced in live human tissue by the same person showing various types of distortions. The left image shows an absence of collapsed arches of the biter, the middle image shows two bite marks in the same area, and the right image also shows two bite marks, one normal bite and one bite produced when the mouth was opened wider. (Sheasby, D. R., & MacDonald, D. G. (2001). A forensic classification of distortion in human bite marks. Forensic Science International, 122, 75-78.).

Many variables affect the appearance of a bite mark wound pattern. If the victim is still alive after the assailant has bitten the victim, time and healing of the wound will greatly influence the appearance of the wound pattern. Over a short period, the bite mark in live human tissue will significantly modify and eventually disappear after thirty-six hours of being produced (Avon & Wood, 2005). Another variable that would greatly affect the wound pattern of a bite
mark is the amount of force the assailant inflicts in producing the wound pattern. Did the assailant bite hard enough to penetrate skin, or was the bite only hard enough to leave bruising? (Sheasby & MacDonald, 2001). If the assailant and/or victim was moving around when the wound pattern was inflicted, the teeth impressions would be modified in the skin and possibly result in tearing or apparent sliding of the teeth, as shown in Figure 3.2 a and b (Internet).

![Figure 3.2 a and b: Bite mark wound patterns in human skin showing the movement of the assailant and/or victim. (Google Images).](image)

Bite mark analysis and comparisons can be different and recently the results of such analysis have been called into question. The current technique for bite mark examinations are based on the interpretation of photographic evidence of the suspected bite wound to the models of teeth from suspects. Even if this technique was able to find teeth impressions that were consistent with the bite mark wound patterns, the wound pattern could have been altered to appear as though another set of teeth impressions produced the wound. For example, if a perpetrator had a missing tooth on his top left side, he could possibly bite a victim twice at slightly different angles and the resulting wound pattern would show that a perpetrator that produced the wound pattern had all teeth. A comparison of the wound pattern to a model of the
suspect’s teeth impressions may result in complicated of unreliable conclusions. Reconstruction of the wound pattern from bite marks would be a technique to use and observe how the wound pattern was produced. This portion of the wound pattern study will examine producing bite mark wound patterns in different types of materials in order to accurately reconstruct bite mark wound patterns similar to those produced in human skin (Sandeep, et al, 2016).
**Procedure**

Molds and teeth impressions of various teeth impressions were made from volunteers of various ages. Alginate, a fast acting molding material (that is safe if ingested or dermal contact) was used to produce the teeth molds. Source: [https://www.cavex.nl/en](https://www.cavex.nl/en). The alginate was purchased in a pink powdered form and water was added in order to form a thick, pink paste. The pink alginate paste was placed in a dental mold plate and placed in the mouth of a volunteer to obtain a dental mold. Once the alginate paste turned from a pink color to white, the alginate paste had hardened, resulting in a solid mold structure as shown in Figure 3.3. Dental stone powder was mixed in a 3:1 ratio with water to form a liquid-like paste, poured into the alginate molds, and allowed to fully harden. The alginate mold was then peeled off of the dental plate and the hardened dental stone, revealing the 3-D dental model, as shown in Figure 3.4 a and b. Top and bottom dental impressions of each volunteer were obtained, and facts listed in Table 3.1.

![Figure 3.3 a and b: Dental mold of the top layer of teeth in hardened Agilent.](image)
Figure 3.4 a and b: The front view of top and bottom sets of dental impressions in dental stone from subject JC (left) and the side view of top and bottom sets of dental impressions in dental stone from subject JC (right).

Table 3.1: Teeth impression samples for bite mark study

<table>
<thead>
<tr>
<th>Name</th>
<th>Male/Female</th>
<th>Age range</th>
<th>Mouth Size</th>
<th>Number of teeth (top)</th>
<th>Number of teeth (bottom)</th>
<th>Number of gaps between teeth</th>
</tr>
</thead>
<tbody>
<tr>
<td>JC</td>
<td>F</td>
<td>Mid 40s</td>
<td>Large</td>
<td>14</td>
<td>14</td>
<td>2</td>
</tr>
<tr>
<td>IJ</td>
<td>M</td>
<td>Late teens</td>
<td>Medium</td>
<td>14</td>
<td>14</td>
<td>0</td>
</tr>
<tr>
<td>MS</td>
<td>F</td>
<td>Mid 20s</td>
<td>Medium</td>
<td>16</td>
<td>N/A</td>
<td>1</td>
</tr>
<tr>
<td>BS</td>
<td>M</td>
<td>Mid 20s</td>
<td>Small</td>
<td>14</td>
<td>14</td>
<td>3</td>
</tr>
<tr>
<td>DR</td>
<td>M</td>
<td>Early 60s</td>
<td>Large</td>
<td>14</td>
<td>N/A</td>
<td>0</td>
</tr>
</tbody>
</table>

Green dental trays were used to hold the dental alginate in place while it hardened around the teeth. There were three different sized dental trays for various mouth sizes, small, medium, and large for various sized mouths. The mouth size mentioned in Table 3.1 correlates with the tray size that was used to make the alginate dental molds.

Once all the dental stone models were made from the teeth molds, they were pushed into various types of materials, including ballistic gelatin, ballistic soap, PermaGel, regular soap, clay,
and pressure-sensitive film. The wound pattern impressions left behind in the different materials were then cast with Mikrosil casting material and compared with one another. Before each of the dental stone models were pushed into the different materials, detailed observations and measurements were conducted, including the width of gaps in between teeth, number of teeth, and the size of teeth. These measurements were compared with the tooth chart, shown in Figure 3.5, to observe which teeth are missing, chipped, or worn down. Some of dental stone models were did not fully set, and some dental models only consisted of top teeth oppressions. A general trend of the observations and measurements of teeth are shown in Table 3.2.

Figure 3.5: An image of where measurements were taken on the subject teeth impressions for Table 3.2. “a” represents the distance from the front teeth (central incisors) to the most posterior teeth (wisdom teeth or 3rd molars); “b” represents the widest width of the teeth impressions, or the distance from the wisdom teeth or distance from 3rd molars; “c” represents the width of the front portion of the impressions, or the distance from the canines.
Table 3.2: Teeth impression measurements of subjects from dental stone models

<table>
<thead>
<tr>
<th>Dental stone models</th>
<th>a</th>
<th>b</th>
<th>c</th>
<th>Wisdom teeth?</th>
</tr>
</thead>
<tbody>
<tr>
<td>DR top</td>
<td>4.9 cm</td>
<td>5.9 cm</td>
<td>4.0 cm</td>
<td>No</td>
</tr>
<tr>
<td>MS top</td>
<td>5.4 cm</td>
<td>5.3 cm</td>
<td>3.7 cm</td>
<td>Yes</td>
</tr>
<tr>
<td>JC top</td>
<td>4.2 cm</td>
<td>5.6 cm</td>
<td>3.7 cm</td>
<td>No</td>
</tr>
<tr>
<td>BS top</td>
<td>4.5 cm</td>
<td>6.1 cm</td>
<td>3.9 cm</td>
<td>No</td>
</tr>
<tr>
<td>IJ top</td>
<td>4.5 cm</td>
<td>5.8 cm</td>
<td>4.2 cm</td>
<td>No</td>
</tr>
</tbody>
</table>

Figure 3.6: Tooth chart to show the name of each tooth and where they are located on the jaw
Results

A large chunk of white modeling clay was flattened and the dental stone model were pushed into the material. When the dental stone teeth oppressions were pulled off of the material, a detailed impression of each tooth was revealed and the overall size of the jaw was determined. Mikrosil was added onto the indentations and allowed to harden. The process of making an impression in the test material, the application of the Mikrosil casting material and the resulting cast is illustrated in Figures 3.7 a, b, and c, respectfully. The Mikrosil was made by adding the Mikrosil silicone with a little hardener and mixed quickly and laid over the indentation. The Mikrosil cast, Figure 3.7 c, revealed detail of the bite mark impression, which is ideal for identifying the assailant that inflicted the wound. There does appear to be holes in some teeth impressions, due to captured air bubbles in small areas when the Mikrosil mixture was added on top of the indentations made in the clay material, where the casting material did not completely fill the tooth indentations.
The same procedure was performed as mentioned above with the dental stone models pushed into ballistic gelatin. Small blocks of ballistic gelatin were reused from the ballistics study, mentioned in Chapter 2. Each dental stone model was pushed into the ballistic gelatin material with light hand pressure, resulting in a bite mark pattern, shown in Figure 3.8 b. The Mikrosil silicone paste was mixed thoroughly with a small amount of hardener and smeared on top of the bite mark pattern in the ballistic gelatin. Due to the consistency of the Mikrosil, along with the smoothness of the ballistic gelatin, there was some difficulty spreading the casting material along and inside the wound patterns before it fully hardened. The bite mark pattern that was produced is shown in Figure 3.8 c.

Permagel is meant to be a substitute for ballistic gelatin, and so bite mark wound patterns were attempted to be produced in this material as well as the ballistic gelatin. A small block of Permagel was obtained from the ballistic study. The same procedure was completed as mentioned before and as a result, no wound pattern was produced from the dental stone models being pushed into the material. Even when the dental stone models were pushed into the material
at full force, there was no indentation or tearing into the material. As a precaution, Mikrosil material was spread around the area where the teeth models were pressed into the material, and no small impression details of the bite marks were found on the casting material when hardened.

A comparison between the elastic-like material (ballistic gelatin) and plastic-like material (ballistic soap) was made. A small block of ballistic soap was obtained from the ballistics study and the teeth oppressions were pushed into the material. The Mikrosil casting material was smoothed over the wound pattern produced in the ballistic soap and hardened. The wound pattern produced from the bite mark models is shown in Figure 3.9. There was a great amount of detail shown in the bite mark wound pattern, showing each individual tooth, as well as observing any gaps between the teeth. The back teeth (first and second molars), show less detail within the wound pattern than the front teeth.

Figure 3.9: Mikrosil cast of bite mark wound pattern produced in ballistic soap.

A small block of regular soap was used as a potential tissue simulant to produce bite mark wound patterns. The teeth oppressions in dental stone were pushed into the material and a wound
pattern was produced, shown in Figure 3.10 a. Some of the soap stuck to the dental stone models, altering the wound pattern that was produced in the material. Mikrosil casting material was spread on top of the wound produced in the regular soap block and allowed to harden. Similar to the ballistic gelatin, the Mikrosil material was difficult to spread over the wound pattern due to the slippery consistency of the regular soap block material. As shown in Figure 3.10 b, the overall outline of the teeth impressions was shown, however no detail or individual characteristics were observed. Noting the positive cast impression of the bite mark wound pattern, it was confirmed that the soap stuck to the dental stone models when the wound pattern was produced, which altered the overall appearance of the wound pattern. It is possible that the impressions in the soap itself could be accurate reproductions of the teeth. There may have been some alteration of the teeth impressions in the soap itself because small bits of the media were stuck on the dental stone teeth models.

Figure 3.10 a and b: Bite marks produced in regular soap (left). Resulting Mikrosil cast producing a positive image of the bite mark (right).

The last material that was used to produce a bite mark wound pattern for a potential tissue simulant was Fujifilm prescale pressure-sensitive film from Fujifilm. Source:
https://www.pressuremetrics.com/. There are three different types of pressure metric films: prescale, UV scale, and Thermo-scale products. This film is clear to white in appearance, and when pressure is applied to the film, a red scale of color indicates the pressure differences. The color intensity indicates the pressure magnitude, concluding that the darker the color, the greater the pressure applied to the tested film. Due to the price of this film and the uncertainty of producing a wound pattern, only a sample of the film was obtained. This prescale film technology determines the pressure distribution and the pressure measurement with an extremely thin and stable film, less than 200 µm thick. The two-sheet prescale film is a single-use film that measures pressure ranges from 0.05 to 300 MPa, or 7 to 43,000 psi. This film captures the pressure profile via color scale and reveals the pressure distribution. This type of film is an easy way to check pressure distribution of materials contacting with other surfaces. As shown in Table 3.3, there are eight different types of pressure-sensitive film, varied based on the amount of pressure being applied to the film. Because the amount of pressure applied to the bite greatly varies, the application specialist from Sensor Products Inc. recommended using the film with the greatest amount of pressure required. The pressure-sensitive film that was used to produce bite mark wound patterns was Super High Pressure (HHS) film, measuring pressures from 120 to 300 MPa (mega pascals). 1 MPa = 145.038 psi (pounds per square inch).
Table 3.3: The eight types of pressure-sensitive film available through Fujifilm and their pressure levels that are indicated.

<table>
<thead>
<tr>
<th>Product</th>
<th>Product Code</th>
<th>Product Size</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Super High Pressure (HHS)</td>
<td>PRESCALE HHS R270 10M</td>
<td>270 × 10</td>
<td>Mono-sheet</td>
</tr>
<tr>
<td>High Pressure (HS)</td>
<td>PRESCALE HS R270 10M</td>
<td>270 × 10</td>
<td>Mono-sheet</td>
</tr>
<tr>
<td>Medium Pressure (MS)</td>
<td>PRESCALE MS R270 10M</td>
<td>270 × 10</td>
<td>Mono-sheet</td>
</tr>
<tr>
<td>Medium Pressure (MW)</td>
<td>PRESCALE MW R270 10M</td>
<td>270 × 10</td>
<td>Mono-sheet</td>
</tr>
<tr>
<td>Low Pressure (LW)</td>
<td>PRESCALE LW R270 10M</td>
<td>270 × 10</td>
<td>Two-sheet</td>
</tr>
<tr>
<td>Super Low Pressure (LLW)</td>
<td>PRESCALE LLW R270 5M</td>
<td>270 × 5</td>
<td>Two-sheet</td>
</tr>
<tr>
<td>Ultra Super Low Pressure (ULLW)</td>
<td>PRESCALE ULLW R270 5M</td>
<td>270 × 5</td>
<td>Two-sheet</td>
</tr>
<tr>
<td>Extreme Low Pressure (4LW)</td>
<td>PRESCALE 4LW R310 3M</td>
<td>310 × 3</td>
<td>Two-sheet</td>
</tr>
</tbody>
</table>

https://www.pressuremetrics.com/.

The pressure-sensitive film was placed on a hard surface (table) and the dental stone models were placed on top of the film and pushed down. Even at full force, the amount of pressure added to the dental models was not enough to produce any pink or red color on the film. Another sample of film was added on top of a block of ballistic gelatin and again the dental stone models were pushed onto the film. When the teeth impressions were pushed into the materials with a large amount of force, the film did turn a light pinkish color, however no wound patterns were observed.
Figure 3.11 a and b: The pressure-sensitive film after the dental model was pushed onto the material when it was on the table (left) and the pressure-sensitive film after the dental model was pushed onto the material when it was on a block on ballistic gelatin (right).

The positive test areas are the pink colored areas shown in Figure 3.11 b. The areas indicated by the arrows are the negative test areas that were not inflicted by the addition of pressure. Air bubbles between the pressure-sensitive film and the ballistic gelatin were apparent in the white areas on the film, as shown by the arrows in Figure 3.11 b. The air bubbles lowered the amount of pressure that was added to the pressure-sensitive film.
Discussion

Each of the bite mark models from the five subjects were pressed into each material and the wound pattern produced were observed and measured. The measurements were compared to those taken from the dental stone model that was made to observe the amount of modification of the wound pattern in the different materials. Because the trend and patterns were the same for all the dental stone models in each material, only the wound patterns produced from the DR subject dental stone models were shown in the following figures.

Mikrosil was an important material used throughout this study for comparing the dental stone model impression to the bite mark wound pattern left produced in the various materials. The Mikrosil casting materials were obtained as a forensic kit from Evident. Source: https://www.shopevident.com/

Due to a wide range of variables the wound pattern of a bite mark can be altered and a reliable comparison often cannot be made. Using the Mikrosil casting material allowed for a positive impression of the wound pattern to be recorded, which led to better documentation of the wound pattern produced in various materials. More accurate measurements of the wound pattern, as well as the observation of the amount of potential pressure that was applied to the wound based on impression depth could be seen from the Mikrosil casts, whereas a photograph of the wound pattern may not be able to give this type of information. Mikrosil is a common casting material used throughout many forensic disciplines to observe toolmark impressions and small details, such as striations, from fired bullets and sliding tool marks. This casting material is available in many different colors, however in this study, brown was the selected color as it showed maximum contrast of details within the wound pattern impressions.
Using the same dental stone models to produce the wound patterns, it can be observed how the different materials influence the appearance of the bite mark based on their physical properties. Figure 3.12 shows the wound patterns produced in the different types of materials to observe how different the bite mark can appear and the importance of finding suitable materials for potential tissue simulates.

Figure 3.12 a, b, c, and d: (From left to right) Positive impressions casted of bite mark wound patterns inflicted by subject DR in clay, ballistic gelatin, ballistic soap, and regular soap.

The bite mark wound pattern produced in clay was observed to appear most consistently with the dental stone model that inflicted the wound. Clay does not have similar elastic properties or density to human tissue, which is why bite mark patterns would not show as much detail of the teeth impressions in human tissue. Although the wound pattern produced in Figure 3.13 (Internet) was not inflicted by the same dental impressions that inflicted the wound pattern in clay, the differences between the wound patterns is significant. The wound pattern shown in Figure 3.13 (Internet) is an example of the detail in bite mark wounds that may be found in human tissue. Due to the elasticity of the human skin and tissue, the area around the bite mark wound is bruised but not lacerated or penetrated, as shown from the wound pattern in clay. In
addition, it is observed that not every individual tooth is shown from the wound pattern produced in the human skin, especially the back molars, unlike the wound pattern produced in the clay material.

Figure 3.13: Detailed bite mark wound pattern in human skin. (Google Images).

One major finding observed in both the wound patterns produced in human skin, as well as the wound patterns produced throughout this study, was that more detail and individual characteristics were observed in the area where the front teeth would have made contact with the material. The front teeth (incisors and canines) on both the maxilla (upper jaw) and mandible (lower jaw) are longer and thinner than the molars in the back of the mouth and are easier to access. These properties effect the appearance of the bite mark wound patterns and are the reason why more details from the incisors are observed verses impressions from the back of the mouth. The same amount of force was used to press the front and back teeth models into different materials, however each time more detail in the front teeth were observed than the back teeth
Because of the smaller surface area, or width of the front teeth (incisors and canines), they are able to penetrate through materials easier than back teeth, resulting in deeper penetration of the teeth into the materials. This observation was seen in the wound patterns produced in the ballistic gelatin. As shown in Figure 3.12 b, there are fewer observable details or individual characteristics compared to the impressions produced in clay, however an overall outline of the wound pattern is consistent with how a bite mark wound pattern would appear in human tissue.

The wound patterns produced by the front teeth were smaller in width than the actual teeth that inflicted the wound, due to the elasticity of the ballistic gelatin. Although less detail and individual characteristics were observed in the wound patterns produced in ballistic gelatin than clay, the wound pattern dimensions and appearance are more consistent with those observed in human skin. Measurements were accurate with those taken from the dental stone models and could be useful in narrowing the possible number of suspects who could have inflicted the wound.

The Permagel was unable to accurately reproduce a wound pattern from the inflicted bite marks in this study. It is known that Permagel is made of a different material than ballistic gelatin in order to make it thermally stable, however it is apparent that the components that make this material provide a greater amount of flexibility in which to inflict wounds of greater depth than ballistic gelatin. Future research should be conducted on the amount of pressure needed to produce wound patterns in Permagel similar in appearance to ballistic gelatin.

In the ballistics study mentioned in Chapter Two, ballistic gelatin and ballistic soap were compared with one another in order to evaluate the difference in permanent and temporal cavities that were produced by the penetrating projectile. The same comparison was made in this bite mark study to observe if the two materials would shown similar results. Figure 3.14 a and b show
the wound patterns produced in the ballistic gelatin and ballistic soap inflicted by the same dental stone model.

Figure 3.14 a and b: bite mark wound patterns inflicted by subject DR in ballistic gelatin (left) and ballistic soap (right).

Regular soap was used as a potential tissue simulant to produce bite mark wound patterns. Like the results in the ballistics study, regular soap was found to be a poor tissue simulant. When the dental stone models were pushed into the material, some of the soap stuck onto the dental models as they were lifted off the block. This result altered the overall wound pattern that was produced. Measurements of the wound pattern produced in the regular soap block were larger and wider than the measurements taken from the dental stone models. The only individual characteristics that were obtained from the wound pattern produced in the regular soap block was an overall outline of the bite mark. This outline of the bite mark impression corresponds somewhat with the size and relative shape of the of the teeth that produced the wound.
The last material used as a potential tissue simulant to produce accurate bite mark wound patterns was the pressure-sensitive film from Fujifilm. This type of material was used in this study to reconstruct a bruise pattern produced from bite marks. Most of the materials used throughout this study only showed potential penetration wound patterns produced from the bite marks, however in human tissue, bruising is the most common type of wound produced. When the film was placed on the table and the dental stone models were pressed onto the film, no wound pattern was produced. This result means that the amount of pressure applied to the film from the dental stone model was less than 100 MPa. However, when the film was placed on a block of ballistic gelatin and the dental stone models were pushed onto the film, almost the entire sample of film changed to a light pink color, shown in Figure 3.10 b.

Two theories were hypothesized based on the results that were obtained from production of the bite mark wound pattern. One theory was that the chemicals within the ballistic gelatin reacted with the color properties of the pressure-sensitive film. The film was said to contain stable chemical compounds and only changed colors when a ranged value of pressure was applied to the film, however it was determined that the film was not previously used in a forensic application and never came in contact with ballistic gelatin before. Future research should be conducted to observe if the compounds or acidity of ballistic gelatin was the reason for the color change in the pressure-sensitive film. This theory was not tested in this research due to the lack of film material available.

Another theory was by pushing the film between the ballistic gelatin and the dental stone model, a significant amount of pressure was added to the film sample, reaching a minimum pressure of 100 MPa. All eight types of pressure-sensitive film should be investigated to determine the potential pressure range inflicted on human tissue from a bite mark.
Dental stone models were used to produce bite mark wound patterns in various types of materials. If bite mark wounds are found on victim’s skin and tissue, the evidence is usually photographed and compared to impressions produced from suspects of the crime. Due to the large number of variables that affect the appearance of a bite mark wound pattern, these types of wound patterns are unique and can be altered very easily. Based on the wound patterns that were produced in the various types of materials in this study, wound patterns produced in clay were closest in appearance to bite mark wound patterns produced in human skin and tissue.
Chapter Four: Blunt Force Trauma Wound Patterns

Introduction

Blunt force trauma is an event which occurs to the body, whereby an instrument contacts the body with great force. Often these types of wounds produce a crushing effect to the body, whether the body fell from a high distance onto a hard surface, or an instrument being swung with a great force and contacting the body. Some blunt instruments consist of hammers, baseball bats, pipes and crowbars. These types of blunt force wounds can be of varying degrees of severity. In certain locations, these blunt force wounds may lead to serious internal injuries, such as blows to the abdomen leading to ruptured liver or spleens. Indicated by the images in Figure 4.1 a and b, blunt force trauma injuries are a combination of abrasions, lacerations, and contusions (Henderson, et al, 2005).

Figure 4.1 a and b: Different types of blunt force trauma wounds inflicted on different persons, a laceration wound most likely caused by making contact with a blunt force object (left), and a large surface area of laceration and crushing wounds with some contusion resulting from falling from a high distance (right). (Google Images).
There are many variables that effect the appearance and severity of blunt force trauma wound patterns. One of the major variables that effects the appearance of a blunt force wound pattern is the amount of force used to inflict the wound. Another significant variable that effects the blunt force wound pattern is the type of object used. The larger the item used, often the larger the wound pattern will be. Other variables, such and the presence of underlying bone structure as the number of times the body was struck and the location of the body that was struck also change the appearance of the wound patterns produced (Batalis & Denton, 2016).

One of the most important reasons to observe and analyze blunt force injures, is to determine the nature and magnitude of force applied to the human skin and tissue. By analysis of blunt force injury wound patterns, fragments of the instrument or object used to produce the wound may be embedded and identified as trace evidence. When analyzing the wound patterns on the victim, the first assessment is to determine if the wound is an abrasion or incised sharp force wound. Certain abrasion patterns that are produced may appear like an incised wound, if the tearing significantly penetrated the skin. Figures 4.2 a and b show how similar abrasions and incised wounds may appear, even though they are produced by different mechanisms. Glass bottles are a very common object to find at a crime scene and are sometimes used as a weapon of choice when other weapons may not be available (Ambade & Godbole, 2006).

Glass bottles are a versatile weapon, as it may be broken and used as a sharp force weapon, or if swung with a large amount of force, could be used as a blunt force weapon. If a glass bottle was used as a sharp instrument, the incised wound patterns produced would have sharp edges around the wound cavity, similar to the wound pattern in Figure 4.2 a (Internet). In comparison, if glass bottles are used as a blunt object and produce laceration-type wounds, the
edges of the effected skin and tissue are rough as shown in Figure 4.2 b (Internet) with tissue bridges spanning the wound opening (Ambade & Godbole, 2006).

Figure 4.2 a and b: The similar appearances in incised wounds (left) and severe laceration wounds (right). (Google Images).

Glass bottles used as weapons are very significant because there has been limited research conducted on glass bottles used as blunt force weapons. In many cases, tiny particles of metal or wood splinters are left behind in the wound, indicating the type of weapon that was used to inflict the wound. This differs from the situation in which glass bottles are the weapons because unless the glass bottle breaks, there is no trace evidence left behind. The patterned injuries from the patterns on bottles can potentially leave behind wound patterns on human skin and tissue. These types of wounds can result in a bruise pattern through a combination of scrapes and tears. The patterns left behind from glass bottles used as blunt instruments produced in human skin give much information about the type of bottle used (Baldwin, 2013).
**Procedure**

Like materials and procedures used in Chapter Three, this study examined blunt force wound patterns using different types of glass bottles produced in clay, ballistic gelatin, ballistic soap, Permagel, regular soap, and pressure-sensitive film. For each of the potential tissue simulants, a Heineken and Cîroc bottle were held by the neck and swung at a downward-angle with the dominant hand onto the materials, which were sitting on a table at waist height. These glass bottles were used for this project because they were available at the time the study was initiated and also because the bottles used had very noticeable and distinctive oppression details on the bottles. Either an illustration or the name the manufacturer of the beverage was oppressed into the glass bottles. As shown in Table 4.1, some other types of bottles, Purple Haze and Gordons Gin, were used to produce blunt force wound patterns in clay and regular soap. These additional types of glass bottles were used due to the large oppression patterns on the bottles. Figure 4.3 a, b, c, and d (Internet) show the different bottles that were used in this study.

To keep certain variables constant, all bottles were swung at a downward angle by a female in her mid-20s and hit onto the materials which were all of the same height. The indentation of the materials produced by hitting it with the bottles, as well as any distinctive impression patterns produced from the details on the glass bottles were measured using a ruler and caliper. The glass bottles were all swung by the neck of the bottle, and the bottles were swung with the glass augmentation pointing toward the potential tissue simulants to observe if the indentations patterns would be found as part of the wound patterns. The simulant was struck at its base using the neck of the bottles as a handle. The bottle was oriented each time so that the design on the bottle would be impressed on the tissue simulant. Measurements of the overall
indentation pattern in the media, as well as the distinctive patterns from the glass patterns were measured and documented.

Figure 4.3 a, b, c, and d: Image of glass bottles that were used throughout the blunt force wound study, from left to right; Heineken beer bottle (12 oz), Cîroc vodka bottle (750 mL), Purple Haze beer bottle (12 oz), and Gordon’s dry gin bottle (1.75 L). (Google Images).

For safety precautions, the study was performed in an isolated room with little to no foot traffic. Safety goggles, a face shield, and proper personal protective clothing were worn in case any of the glass bottles broke. A protective tarp was laid around the area where the study was to be performed to better observe any glass fragments.
Results

A summary of measurements and observations from the blunt force wounds produced in various types of potential tissue simulants are shown in Table 4.1. When the bottles were swung onto the different materials, listed below, only the regular soap, clay, and ballistic soap produced any pattern impressions. No indentations or distinct patterns were produced in the other materials, Permagel, ballistic gelatin and pressure-sensitive film, and therefore were determined not to be suitable as tissue simulants for the reconstruction of blunt force trauma wound patterns produced by glass bottles.
Table 4.1: Summary of wound pattern measurements and observations produced in different materials.

<table>
<thead>
<tr>
<th>Bottle Used</th>
<th>Wound Pattern Produced?</th>
<th>Length of wound</th>
<th>Width of wound</th>
<th>Distinctive patterns from glass in wound pattern?</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Regular Soap</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Purple Haze</td>
<td>Y</td>
<td>7.7 cm</td>
<td>3.2 cm</td>
<td>N</td>
</tr>
<tr>
<td>Heineken</td>
<td>Y</td>
<td>11.0 cm</td>
<td>4.8 cm</td>
<td>N</td>
</tr>
<tr>
<td><strong>PermaGel</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cîroc</td>
<td>N</td>
<td>N/A</td>
<td>N/A</td>
<td>N</td>
</tr>
<tr>
<td>Heineken</td>
<td>N</td>
<td>N/A</td>
<td>N/A</td>
<td>N</td>
</tr>
<tr>
<td><strong>Clay</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cîroc</td>
<td>Y</td>
<td>N/A</td>
<td>6.5 cm</td>
<td>Y (oval with design in center)</td>
</tr>
<tr>
<td>Gordons</td>
<td>Y</td>
<td>10.5 cm</td>
<td>5.7 cm</td>
<td>Y (ONS letters)</td>
</tr>
<tr>
<td>Heineken</td>
<td>Y</td>
<td>11.3 cm</td>
<td>4.5 cm</td>
<td>Y (Star and “nekenie” underneath)</td>
</tr>
<tr>
<td>Purple Haze</td>
<td>Y</td>
<td>10.1 cm</td>
<td>3.4 cm</td>
<td>Y (circular indentation pattern from bottom edge of bottle)</td>
</tr>
<tr>
<td><strong>Ballistic Soap</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cîroc</td>
<td>Y</td>
<td>N/A</td>
<td>N/A</td>
<td>Y (oval with design in center)</td>
</tr>
<tr>
<td>Heineken</td>
<td>Y</td>
<td>11.1 cm</td>
<td>5.9 cm</td>
<td>Y (“neke” letters)</td>
</tr>
<tr>
<td><strong>Ballistic Gelatin</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heineken</td>
<td>N</td>
<td>N/A</td>
<td>N/A</td>
<td>N</td>
</tr>
<tr>
<td>Cîroc</td>
<td>N</td>
<td>N/A</td>
<td>N/A</td>
<td>N</td>
</tr>
<tr>
<td><strong>Pressure-Sensitive Film</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heineken</td>
<td>N</td>
<td>N/A</td>
<td>N/A</td>
<td>N</td>
</tr>
<tr>
<td>Cîroc</td>
<td>N</td>
<td>N/A</td>
<td>N/A</td>
<td>N</td>
</tr>
</tbody>
</table>
Table 4.2: Dimensions of the glass bottles used in this study.

<table>
<thead>
<tr>
<th>Bottle</th>
<th>Base length</th>
<th>Base width</th>
<th>Shape of Base</th>
<th>Length of Neck</th>
<th>Width of Neck</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heineken</td>
<td>14.0 cm</td>
<td>5.6 cm</td>
<td>Cylindrical</td>
<td>8.5 cm</td>
<td>2.6 cm</td>
</tr>
<tr>
<td>Cîroc</td>
<td>26.6 cm</td>
<td>7.0 cm</td>
<td>Cylindrical</td>
<td>5.2 cm</td>
<td>3.2 cm</td>
</tr>
<tr>
<td>Gordon’s</td>
<td>21.1 cm</td>
<td>8.4 cm</td>
<td>Square-ish</td>
<td>9.0 cm</td>
<td>3.1 cm</td>
</tr>
<tr>
<td>Purple Haze</td>
<td>12.5 cm</td>
<td>5.75 cm</td>
<td>Cylindrical</td>
<td>7.1 cm</td>
<td>2.6 cm</td>
</tr>
</tbody>
</table>

A wound pattern was defined by two observations within this study. The first wound pattern that was searched for was an indentation of the overall glass bottle, where the width of the bottle could be measured, as well as the length of the wound pattern that was indented within the media. The second wound pattern that was searched for was the distinctive patterns left behind by the glass oppressions on the glass bottle.

An unintended variation in the procedure was made by the person striking the glass bottle against the various simulants in that the bottles were struck only once against the materials instead of multiple times. Once this mistake was noticed, the ballistic gelatin was found to be a gelatinous liquid from a malfunction in a smaller cold storage room and was unable to be tested on. Therefore the glass bottles were unable to be struck in the same media more than one time. Ideally, each glass bottle would be struck into each medium a minimum of three times so statistical measurements could be observed.
Figure 4.4 a and b: Wound patterns of a Heineken beer bottle (left) and Gordon’s gin bottle (right) produced in clay and showing the distinctive indentations from the bottles.

With the modeling clay that was used throughout this study, the Heineken glass bottle did slightly stick to the material as it was swung down and made contact. The glass bottle did not break or fragment with contact of the clay material or any other material used in this study other than the pressure-sensitive film. The Heineken bottle broke when it was swung onto the pressure-sensitive film that was placed on the waist-high table. The glass bottle made contact with the clay material toward the front portion of the beer bottle, where the label was located. Right below the neck of the beer bottle was a glass pattern augmentation of a star and the brand “Heineken”. An overall outline of the glass bottle also formed an indentation pattern in the clay material, which was measured and summarized in Table 4.1. Along the bottom of the wound pattern produced in clay was the bottom edge of the bottle, producing patterns from the circular augmentations on the bottom of the bottle, as well as numbers and symbols under the beer label.
The Gordon’s gin bottle was held by the neck, but held in a position that the side of the bottle was facing the clay material, having an augmentation pattern of letters “GORDONS” down the side. The shape of the Gordon’s gin bottle was larger and shaped differently than the Heineken bottle, resulting in a different overall shape of the wound patterns produced.

The wound patterns produced in the regular soap were less well-defined than those produced in clay, as shown in Figures 4.5 a, b, and c. The blunt force wound patterns that were produced in the regular soap show no distinctive indentation patterns that were on the glass bottles. An overall indentation of the glass bottles was produced as the wound patterns in the regular soap. Figure 4.5 b shows very little indentation patterns produced in the material by the Purple Haze beer bottle, whereas the wound pattern produced by the Gordon’s bottle was significantly large and deep, especially near where the bottom edge of the bottle made contact.
with the material. The wound pattern produced by the Gordons bottle did form an indentation of the punt portion of the bottle (the indentation at the base of the bottle, mostly found in wine bottles); giving some individual characteristics of the type of bottle that was used to inflict the blunt force wounds.

Figure 4.6 a and b: Blunt force wound patterns produced in ballistic soap from a Heineken beer bottle (left) and Cîroc bottle (right).
Figure 4.7: Magnified view of the distinct oval pattern with a rooster weather-vane type shape on the glass of a Cîroc bottle (Google Images).

Figure 4.8: Magnified view of the distinct augmentation pattern on a glass Heineken beer bottle of a five-point star with “Heineken” underneath. (Google Images).
Figure 4.9: Magnified view of the distinct augmentation pattern on a glass Purple Haze beer bottle of a wheat or barley symbol and “ABITA” on either side. (Google Images).

Figure 4.10: The bottom of the Cîroc liquor bottle showing the specific circular augmentation patterns, as well specific letters and symbols
In Figure 4.6 a, a Heineken bottle was swung by the neck and hit against the potential tissue simulant, producing the wound pattern shown. There was no bottle indentation left behind, however the “eken” from the distinct glass patterns were produced in the wound pattern. In Figure 4.6 b, there was an oval-shaped pattern with a design on the inside that was produced when the Cîroc bottle was hit against the ballistic soap. A closer view of the distinct pattern on the Cîroc bottle is shown in Figure 4.7.
Discussion

These specific glass bottles were chosen for this study due to their distinct glass augmentation patterns. These patterns would be easily observed and distinguished in a blunt force wound pattern, as well as be easily compared with patterns produced from other glass bottles. Figures 4.7-4.10 (Internet) show the distinct augmentation patterns on the glass bottles that were used throughout this study. The small circular augmentation patterns on the bottom of the bottles were also observed in many of the wound patterns produced in the various types of potential tissue simulants. These tiny circles on the bottom of glass bottles were added in order to add strength to the bottom of the bottles and lessen the chance of the bottle breaking if set on hard surfaces. This is the same reason why wine bottles or other large glass bottles have the large indentation, or punt, on the bottom of the bottle. Different types of bottles will have distinct circular patterns on the bottom of the bottle based on the size and shape of the bottle, as seen on the bottom of the Gordons bottle in Figure 4.5 c. Along the bottom portion of the bottles there are usually a series of numbers and symbols that are augmented onto the glass bottles. These numbers and symbols will potentially produce indentations in blunt force wound patterns, as shown in Figure 4.4 a. These series of symbols and numbers may help to identify the glass bottle that inflicted the wound because these could lead to identifying the batch of beer that bottle was taken from, as well as other manufacturer and production information (Wormer, et al, 1964).

The pressure-sensitive film may be a useful tissue simulant for the reconstruction of wound patterns involving blunt force impact, which may resemble bruising in living tissue. The pressure range to produce various types of wound patterns are determined, as well as observe any type of bruising patterns that may occur. As previously determined in the bite mark wounds
chapter, the pressure-sensitive film required a larger amount of pressure to change the film color from colorless to pink. Although this finding was known when the blunt force section was performed, the samples were still used to observe if glass bottles provided a large enough range of pressure to produce wound patterns on the film. None of the glass bottles were able to produce any type of wound pattern or color change on the pressure-sensitive film. Future research should be conducted on producing different types of wound patterns onto pressure-sensitive film of a smaller pressure (i.e., more sensitive) range.

The wound patterns produced in the different materials had some similarities and differences to the measurements and observations, based on the type of glass bottle that was used to inflict the wounds. A comparison of the wound patterns inflicted by the Heineken bottles in clay, regular soap, and ballistic soap were compared; the measurement values shown in Table 4.1. The Heineken glass bottles produced similar wound patterns in all three of the potential tissue simulants, although the overall indentation pattern of the glass bottle was barely visible in the ballistic soap. As shown in Table 4.1, the Heineken bottle produced an indentation of about 11 cm in length and 4.5 cm in width around where the bottom edge of the bottle would have made contact with the materials. There are some variations to these measurement between the wound patterns produced in the different potential tissue simulants, and therefore should continue to be studied to validate these findings. As observed from the measurements in Tables 4.1 and 4.2, the indentation measurements that most closely correspond to the bottle dimensions was the Heineken bottle. The wound pattern dimensions were similar in value when produced in the regular soap, clay, and ballistic soap, as shown in Table 4.1. After comparing the wound pattern dimensions produced from the various types of glass bottles in the different media, the bottle dimensions of the Heineken bottle have the closest correspondence to the dimensions
measured from the wound patterns. This could be due to the long neck of the glass bottle. The long neck allowed the bottle to be swung easier and the base was able to make contact with the media better than the bottles that had short neck lengths. The glass bottles that produced very different results in each of the materials were the Cîroc liquor bottle and the Purple Haze beer bottle. The wound patterns produced in the regular soap varied with the wound patterns produced in the clay material for both the Purple Haze and Cîroc bottles. As shown in Table 4.1, the length dimension values of the wound patterns produced by the Purple Haze glass bottle vary when produced in the regular soap compared to the clay. It is possible that the length of the neck on the glass bottles influenced the findings from this study. The Heineken bottle had a very long glass neck on the bottle that allowed for optimal holding and swinging onto the various materials, whereas both the Purple Haze and Cîroc bottles had very short necks and was very difficult to hold while attempting to produce blunt force wound patterns.

Although the overall indentation patterns of the glass bottles were similar in appearance and measurements in clay and regular soap, the distinct patterns on the glass bottles were not observed in the regular soap. Based on the results from the blunt force study, it was found that the clay and ballistic soap material were possible tissue simulants for reconstructing blunt force trauma wound patterns with glass bottles. These materials produced some overall indentations from the glass bottles themselves, as well as producing distinctive indentation patterns augmented on specific glass bottles.
Chapter Five: Sharp Force Wound Patterns

Introduction

Sharp force trauma is the leading cause of homicidal death in many countries such as Australia, United Kingdom, and Sweden, and the second leading cause of homicidal deaths in the United States. The most common type of weapon that inflicts these types of wound patterns are knives, however other common types of items such as broken bottles, icepicks, and screwdrivers can also inflict sharp force wound patterns in human skin and tissue. Sharp force injuries are categorized based on the ability of an instrument to produce a well-defined traumatic separation of tissue. There are three types of wound patterns that could be produced by a knife penetrating human skin and tissue; incised wounds, stab wounds, and chop wounds, shown in Figure 5.1 a, b, and c (Bleetman, et al, 2003).

Incised wound patterns are produced from a weapon with a sharp cutting edge and appear as cuts or slashes, cutting through the full thickness of the skin. The type of weapons or instruments that produce incised wounds are knives, razors, and edges of broken glass, and sharp-edged cutting instruments. Incised wound patterns are usually produced on human limbs as defensive wounds from the victim trying to defend themselves. Sharp instruments with a sharp point and a lengthy sharp edge produce stab wounds. These types of weapons that cause incised wound are where the length of the injury is longer than the depth of penetration into the human skin and tissue. The type of weapons that have the ability to produce stab wounds are needles, knives, swords, letter openers, scissors, and ice picks (Anonymous, 2016).

Chop wounds are produced with heavy instruments with a cutting edge such as an ax, machete, or meat cleaver and produce a wound pattern similar in appearance to an incised
wound. One of the main differences between the two wound patterns is that chop wounds can produce underlying fractures within the tissue or deep grooves within the bone. Individual characteristics of the type of chopping wound can be imparted by the manner in which the perpetrator handles the heavy instrument is taken out of the human tissue. Sharp twists required to pull the weapon out of the embedded bone and tissue could potentially give rise to other characteristics (Mussen, 2019).

Figure 5.1 a, b, and c: Different types of sharp force wound patterns produced in human skin and tissue; (from left to right) Incised wound patterns on a forearm produced from a knife (left), stab wounds produced from broken glass during a breaking and entering (middle), and chopping wounds in the head and face area produced from a machete (right). (Bleetman A., Watson C.H., Horsfall I., Champion S.M. (2003, ‘Wounding patterns and human performance in knife attacks: optimizing the protection provided by knife resistant body armor’, Journal of Clinical Forensic Medicine 10(4) 243-248).

There are many variables that effect the production of a sharp force wound pattern. During criminal investigations, particular variables are of interest such as determining the degree
of force inflicted and characteristics of the cutting instrument. Specific wounds inflicted on a
victim can potentially help to identify the nature of the attack. A perpetrator that knew the victim
and wanted to inflict great harm most likely commits wounds with a great amount of force
associated and stabbing and hitting necessitates close contact between victim and suspect. A
better understanding of how the crime was committed, and the type of sharp force instrument
used to inflict the wound, would be helpful in reconstructing the crime. A few different types of
knives are shown below in Figure 5.2 a, b, and c (Internet), differentiated based on knife edge
types, blade shapes, and edge patterns. Limited research has been conducted on the
reconstruction of sharp force wound patterns even though there is a high percentage of homicidal
deaths caused by sharp force weapons. Figure 5.3 shows the results that were found on the
reconstruction of incised wound patterns produced in clay with knives of different edge types
from previous research (Anonymous, 2016). The incise wound patterns produced in the clay
were then compared to a crime scene photograph of an incised wound pattern produced in human
skin from a single-edge knife. This comparison can be seen in Figures 5.3 and 5.4. This sharp
force wound pattern study used a comparison process similar to Figures 5.3 and 5.4, however the
wound patterns produced in different types of materials were compared in ballistic gelatin,
ballistic soap, Permagel, regular soap, and clay (Mussen, 2019).
Figure 5.2 a, b, and c: A few examples of the variability in knives, observing different types of edge types (top), knife blade shapes (bottom-left) and edge patterns (bottom-right) that effect the wound pattern produced in human tissue and skin. (Google Images).
Figure 5.3: Incised wound patterns produced in clay with knives of different edge types, double-edge knife and single-edge knife. (Google Images).

Figure 5.4: Incised wound pattern produced in human tissue from a single-edge knife. (Google Images).
Procedure

There is some research on incised wound patterns and it is hoped that this project will add to this body of knowledge. The materials that were used throughout this sharp force wound patterns section were ballistic gelatin, ballistic soap, Permagel, regular soap, and clay. Four types of knives were used to create the wound patterns in the tissue simulants using knives commonly found in everyday use: a serrated butter knife, a pocket or survival knife, a serrated steak knife, and an un-serrated steak knife. Specific measurements of the knives were taken in order to be compared with the measurements taken from the stab wound patterns, summarized in Table 5.1.
Figure 5.5 a, b, c, and d: Images of the knives used throughout the stab force wound patterns section. Top (left) serrated butter knife, top (right) pocket or survival knife, bottom (left) serrated steak knife and bottom (right) un-serrated steak knife.
Once the stab wound patterns were produced in the different materials, Mikrosil casting material was pushed inside of the wound to cast the details of the wound cavity. The wound cavities were so thin in each of the wound patterns that the Mikrosil material was unable to fit into the thin cavity. To observe the wound patterns that were produced in the various materials from the knives, large slice wounds, were produced instead of the stab wounds in each material. These wound patterns were casted using Mikrosil and were observed and compared under a comparison microscope. The wound pattern casts that were produced in the different materials from the same knife were compared, as well as the wound patterns inflicted by the different knives in the same material. After this study was completed, it was found that the material

<table>
<thead>
<tr>
<th>Name</th>
<th>Materials</th>
<th>Handle length</th>
<th>Blade length</th>
<th>Point at end of blade?</th>
<th>Cutting edge length</th>
<th>Serrated edge?</th>
<th>Teeth length</th>
<th>Teeth Width</th>
</tr>
</thead>
<tbody>
<tr>
<td>Butter Knife</td>
<td>Wood handle, stainless steel</td>
<td>11.0 cm</td>
<td>10.5 cm</td>
<td>N</td>
<td>9.0 cm</td>
<td>Y</td>
<td>1 mm</td>
<td>4 mm</td>
</tr>
<tr>
<td>Pocket/Survival Knife</td>
<td>Stainless steel</td>
<td>10.0 cm</td>
<td>8.7 cm</td>
<td>Y</td>
<td>8.25 cm</td>
<td>Half</td>
<td>3 mm</td>
<td>2-6 cm</td>
</tr>
<tr>
<td>Steak Kitchen Knife</td>
<td>Plastic handle, stainless steel</td>
<td>10.5 cm</td>
<td>7.8 cm</td>
<td>Y</td>
<td>6.85 cm</td>
<td>Y</td>
<td>2 mm</td>
<td>5 mm</td>
</tr>
<tr>
<td>Straight Kitchen Knife</td>
<td>Plastic handle, stainless steel</td>
<td>11.5 cm</td>
<td>12.65 cm</td>
<td>Y</td>
<td>11.0 cm</td>
<td>N</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Table 5.1: Knife measurements and individual characteristics
needed to be sectioned after the stab wound was produced in order to cast and observe the stab wound patterns.
Results

The following Figures are images of casts taken from the chopping wound patterns in the different materials.

Figure 5.6 a, b, c, d, and e: Mikrosil casts of sliced wound patterns inflicted by the serrated butter knife in the potential tissue simulants. From left to right: regular soap, clay, ballistic soap, ballistic gelatin, and Permagel
Figure 5.7 a, b, c, d, and e: Mikrosil casts of sliced wound patterns inflicted by the pocket or survival knife in the potential tissue simulants. From left to right: regular soap, clay, ballistic soap, ballistic gelatin, and Permagel.

Figure 5.8 a, b, c, d, and e: Mikrosil casts of sliced wound patterns inflicted by the serrated steak knife in the potential tissue simulants. From left to right: regular soap, clay, ballistic soap, ballistic gelatin, and Permagel.
Figure 5.9 a, b, c, d, and e: Mikrosil casts of sliced wound patterns inflicted by the un-serrated steak knife in the potential tissue simulants. From left to right: regular soap, clay, ballistic soap, ballistic gelatin, and Permagel

The casts of the wound patterns were then compared under a comparison microscope to observe the wound patterns produced by the same knife in different materials to observe the consistency of the dimensions and striations produced. Knife patterns produced in the same type of materials by different knives were also compared to observe if different types of knives produce patterns so similar as to be undifferentiated. Striation patterns were aligned as best as possible to observe the consistency of the wound patterns from one tissue media to the next, comparing marks made by the same knife.
Figure 5.10 a, b, c, d, and e: Close-up view under comparison microscope of striated patterns inflicted by serrated butter knife in the potential tissue simulants. From left to right: Permagel, ballistic gelatin, ballistic soap, clay and regular soap.

Figure 5.11 a, b, c, d, and e: Close-up view under comparison microscope of striated patterns created by the un-serrated steak knife in the potential tissue simulants. From left to right: ballistic soap, ballistic gelatin, clay, regular soap, and Permagel.
Figure 5.12 a, b, c, d, and e: Close-up view under comparison microscope of striated patterns created by the serrated steak knife in the potential tissue simulants. From left to right: Permagel, ballistic gelatin, regular soap, clay, and ballistic soap

Figure 5.13 a, b, c, d, and e: Close-up view under comparison microscope of striated patterns created by the serrated portion of the pocket or survival knife in the various tissue simulants. From left to right: Regular soap, ballistic gelatin, Permagel, ballistic soap, and clay
Figure 5.14 a, b, c, and d: Close-up view under the comparison microscope of striated patterns produced in ballistic gelatin inflicted by various types of knives. From left to right: Serrated steak knife, un-serrated steak knife, serrated potion of the survival knife, and the serrated butter knife.
Discussion

The major problem with the sharp force wound pattern reconstruction was that the stab wound patterns could not be cast using Mikrosil due to the extremely thin wound cavities produced. Future research should be conducted on the reconstruction of stab wound patterns and different types of casting materials should be experimented with to find a material thin enough to observe details within thin cavities or investigate alternative sample preparation methods such as slicing along the wound track to expose the tool mark inside. In order to obtain some results from the sharp force wound section, slice wounds or deep incised wounds were observed instead. Within the slice wound cavities in human tissue and bone, there are specific patterns that give individual characteristics about the type of weapon that was used, which was observed in this section. Limited observations of slice wounds in tissue has prevented extensive characterization of these types of implements.

Throughout this research, it is observed that the striation patterns produced by the different types of knives were very significant in individualizing the wound patterns produced in the different materials. Observing each cast that was made from the slicing wound pattern shows the knife pattern in each material. For example, the casts shown in Figure 5.6 a, b, c, d, and e, striation patterns are seen in each material, however the pattern is seen easier when produced in the ballistic gelatin and ballistic soap than the other potential tissue simulants.

Striation patterns are generally known as fingerprints for toolmarks because the patterns are specific to one type of tool. Striation patterns are a type of individual characteristic that is produced from contact between an object and a medium. Striation patterns are commonly observed on doors from a crowbar during a breaking and entering investigation, or on a pipe
from a pair of pliers in a pipe bomb explosion investigation. During the manufacturing process, obvious patterns are left on a tools surface from the machines producing that tool, however the more the tool is used, the more nicks and other individual characteristics are added to the tool. This same concept also applied to knives, a different type of tool that is used for precisely cutting other items. Because striation patterns were observed in most of the wound patterns that were produced in this section, a closer observation was made using a comparison microscope to better observe the striation patterns. A closer observation of the striation patterns can be distinguished to a specific type of tool that was used to create those striation patterns on a soft surface (Baldwin, et al, 2013).

A comparison microscope is a type of binocular compound microscope that allows analysis of side-by-side specimens. The two compound microscopes are connected by an optical bridge. In the forensic field, comparison microscopes are mostly used to compare fired bullets and cartridge cases, as well as tool mark examinations, which includes the comparison of knife striation patterns (Thoerner, 1913).

The wound pattern casts produced by the same knife but produced in different potential tissue simulants were compared to each other, as shown in Figures 5.10 through 5.13. As observed from these figures, it is easy to compare wound patterns produced in any of the materials that were inflicted by serrated-edge knives. Cartilage and to a lesser extent bone are capable of recording striations, and it is more likely that the wound patterns would appear similar to those produced in the regular soap, clay, or Permagel. With the serrated-edged knives, these types of potential tissue simulants still produce distinguished striations patterns, they lack the same degree of detail as striated patterns produced by knives in other media. This can be complicated by wound patterns produced in bones, cartilage, and tissue, the hardness and density
of the different materials could alter the overall appearance of the wound pattern. The wound patterns inflicted by the un-serrated steak knife was more difficult to compare due to a lack of details within the wound pattern, especially when produced in the regular soap, clay or Permagel. Overall, the wound patterns produced by the un-serrated knives had less striation detail than the wound patterns produced from the serrated-edged knives, with the exception for the small patterns observed from the nicks and scratches on the blade.
Chapter Six: Electrical Wound Patterns

Introduction

Electrocution fatalities can potentially be difficult to investigate due to the broad range of causes and injuries that may occur, often requiring a specialized knowledge of forensic medicine and electricity. Many electrical injuries are accidental, often occurring with young children with relatively few cases of electrical injuries caused by suicide or homicide. There are two primary types of electrocution events which differ based on the amount of voltage that is passed through the body and the resulting severity of the injury; low voltage electrocution (120-999 V) and high voltage electrocution (greater than 1000 V) (Blumenthal, 2014).

Because of the increasing number of tools in modern society with electrical power, there has been a greater number of electrical injuries, and therefore more research is needed on electrical wound patterns. There are three categories of electrical injuries that may occur; true electrical injuries, flash burn, and flame or burn injuries. True electrical injuries occur when the person becomes part of the circuit, resulting in muscle contractions and may lead to cardiac arrest if the electrical current is of high voltage. Flash burns are produced from current arcs across the body, causing thermal injuries such as blistering or electrical burn patterns. Burn injuries occurs when the electrical current is passed through the ohmic conduction (or the movement of mobile electrons) in the conduction bands. If the electrical current is passed through living human tissue that is covered with clothing, the wound may become more severe and lead to heating and burning of the clothing and tissue (Blumenthal, et al, 2014).
One type of weapon that is intended on electrocuting the human body are Tasers. This type of weapon fire small barbed darts that puncture through the skin in order to remain attached to the target. The darts are made of a thin insulated copper wire that connects to the main unit, shown below in Figure 6.2 (Internet). The main unit delivers a controlled amount of electric current designed to immobilize the target by disrupting voluntary control of muscles. This weapon was produced as a less-lethal option than firearms for police to use on aggressive and potentially dangerous people. One of the major concerns that arise with the use of Tasers are that people with known medical problems, especially involving the heart, are at a higher risk of fatality if a Taser is used on them, compared to a healthy individual. When an autopsy is performed on individuals that passed away shortly after a Taser was used on the victim, the examination of the body must be closely examined for wound patterns and cause of death consistent with coming into contact with a high voltage source of electricity. Tasers are a new technology and therefore many studies have not been conducted on the type of wound patterns that are inflicted on the body. This part of the study observed the wound patterns that were
produced from a Taser-like device used on ballistic gelatin, ballistic soap, Permagel, clay, regular soap, golden rod paper, and thermal-changing pigment (Taylor, 2009).

![Image of a Taser-like device](image)

Figure 6.2: Vipertek VTS-989 Heavy Duty Taser-like device. (Google Images).

The Taser-like device as shown in Figure 6.2, also known as a stun gun, have two prongs for direct contact with the skin. These devices are used to immobilize an attacker without causing serious injury, by administering an electric shock. These compact handhends are small and easily concealed.
**Procedure**

In the state of New York, where the study was conducted, Tasers cannot be purchased online and the police departments within a 30-mile radius of Buffalo, NY no longer carry or use Tasers in their departments. In order to obtain a usable Taser to create the wound patterns in the different materials, one needed to be made. A simple “You- Tube” video was found that gave instructions and what materials would be needed in order to manufacture a “400,000 Volt” Taser. A “DC 3V-6V bis 400kV boost set up power module generator” with four wires was obtained from Yosoo, shown in Figure 6.3 (Internet) Source: [http://www.yosoodirect.com/yosoodirect/](http://www.yosoodirect.com/yosoodirect/).

The negative wire on the input side of the power module was connected to the positive wire of a battery cap, capable of fitting a 9 Volt battery. The exposed wires were twisted together and then covered with electrical tape. The negative wire from the battery cap, as well as the positive wire from the power module were connected to a switch and the exposed wires twisted and covered with electrical tape. The entire apparatus was placed in a cardboard tube with a small opening for the switch to be placed. The 9 Volt battery was placed on the battery cap and the entire apparatus was covered in electrical tape to ensure the wires would not disconnect. The two wires on the output side of the power module were placed on the outside of the unit and placed in a fixed position so that the exposed wires were not touching. The final product is shown in Figure 6.4.
Figure 6.3: An image of a DC Boost step-up power module high-voltage generator by Yosoo used to make a handmade Taser-like device. (Google Images).

Figure 6.4: The final product of the handmade Taser-like device based on the You-Tube video https://www.youtube.com/watch?time_continue=25&v=leBkiako6X4&feature=emb_logo

After the Taser was made and functional, the “electrodes”, or the exposed wires, were placed on the different materials and allowed the electrical current to flow. An image like the
electrical arc produced from the homemade Taser is shown in Figure 6.5. The intention of this part of the study was to record, document and measure any wound patterns produced by the homemade Taser of the tissue simulants.

Figure 6.5: An image of a Taser making an electric arc between its two electrodes. (Google Images).
Results

No wound patterns of any kind were produced in the ballistic gelatin, ballistic soap, regular soap, Permagel, clay, or golden rod paper. A small wound pattern was produced in the thermal-changing pigment, however it is unknown if the wound pattern was produced from the released heat coming off the electric arc, or if the wound pattern was actually inflicted from the electrical current. The area that was affected by the Taser turned from a blue color to a light blue to white color.

Figure 6.6: The wound pattern produced in the thermal-changing pigment after contact by the Taser-like device, changing the pigment from a blue to white color.
Discussion

The two types of potential tissue simulants that were not previously used in any other study were the golden rod paper and the thermal-changing pigment. Golden rod paper is a piece of special paper that contains dyes that react to pH change, similar to litmus paper. The paper is an orange-yellow color in neutral conditions and turns a blood-red color in the presence of a base, shown in Figure 6.7. Although used mostly for various acid-base experiments, it has also been known to show electrical patterns when exposed to electrical currents. Based on the findings from this electrical wound study, no wound pattern was produced in the golden rod paper and therefore was not an ideal tissue simulant for the reconstruction of electrical wound patterns. The thermal-changing pigment was added as a potential tissue simulant to this study after electrical wound patterns were not produced in any of the other materials. Although the powder remained inside its plastic container, the non-toxic powder has been used for a variety of arts and crafts and is miscible in many types of paints, resins and many other solutions. The pigment powder is temperature activated and changes colors at 31°C.

Figure 6.7: Golden rod paper with a color change from yellow to red in the presence of a high pH. (Google Images).
None of the other potential tissue simulants, other than the thermal-changing pigment produced an electrical wound pattern. It is hypothesized that the voltage of the handmade Taser was not of a high enough voltage for any electrical wound pattern to occur and/or the materials used were all significant insulators or the materials were too temperature insensitive to produce a noticeable change. More research should be conducted in finding other tissue simulants that might replicate an electrical injury.

Figure 6.8: Thermal-changing pigment changing from a color to white when an object with a temperature of over 31°C comes into contact. (Google Images).
Chapter Seven: Blood Spatter Experiments

Blood spatter patterns are an important aspect in the determination of events during a crime. These types of patterns can suggest what type weapon was used, the relative position of the victim and perpetrator, and the amount of force that was used to inflict the wounds.

In the beginning process of this reconstruction project, three Styrofoam heads were obtained and the heads were hollowed out where the brain would be located. Three different types of ballistic heads were made and fired at from a distance of three feet away using a 9 mm Luger firearm. The first head was filled with ballistic gelatin and a plastic bag of Halloween blood was placed in the middle of the ballistic gelatin. The second Styrofoam head was prepared the same way, moreover a short-haired wig was added on top of the head. The third Styrofoam head was also filled with ballistic gelatin, however the Halloween blood was added to the liquid gelatin mixture during mixing and hardening, before being placed into the head mold. The Styrofoam heads were fired at during an indoor gun range session. A white paper panel was placed behind the Styrofoam heads and the blood spatter patterns were collected. A complication occurred during this section of research and the blood spatter patterns were compromised, mentioned below. Due to time restraints and available resources, the blood spatter section of this project remained incomplete.
Figure 7.1: Example of experimental set-up of blood simulant and ballistic gelatin filled Styrofoam head at shooting range.
Figure 7.2 a and b: An image of the Styrofoam head hollowed-out and filled with solidified chunks of ballistic gelatin with a bag of Halloween blood in the middle. The top portion of the Styrofoam head was placed back on and taped down. Two of the three heads were produced in this manner. A short-haired wig was placed on one of the Styrofoam heads.

Figure 7.3 a and b: An image of the Halloween blood mixed in with the cooling liquid ballistic gelatin and allowed to solidify. The mixture was also added to the top of the head as well. Once the gelatin mixture was solidified, the top of the head was taped down.
The three Styrofoam heads were placed on a table in the Wolcott, INC indoor gun range in Depew, NY. The heads were fired at using a Glock 17 gen 4 with 9mm Luger hollow point bullets and fired from a distance of three feet (91.44 cm). The first Styrofoam head that was fired at required two fired bullets because Cliff Schlemmer, the shooter, fired directly below the lip which was lower than the ballistic gelatin. Another round was fired directly on the nose, producing a wound pattern as shown in Figure 7.4 a and b.

Figure 7.4 a and b: The entrance and exit wound patterns produced in the Styrofoam head with the wig on top of it from a fired 9mm hollow point round from three feet away.

The other portion of the project that was not mentioned in this report was medical moulage. Medical moulage, or sometimes called CSI makeup, is the art of applying mock
injuries for the purpose of training emergency repose teams, realistic theatre acts, and accurate observations of wound patterns during court testimonies. Medical moulage would take the reconstruction of wound patterns one step further than tissue simulants in order for the wounds to appear realistic during court testimonies.

Figure 7.5: An image of the back spatter blood patterns produced from the Styrofoam head with the wig on top with wound patterns shown in Figure 7.4 a and b.

The blood spatter pattern is very small droplets and trailing focused around the bottom right corner of the paper panel. There were very small chunks of ballistic gelatin found stuck on the larger droplets of blood on the paper panel. There also appears to be stray hairs that were stuck on the paper panel. The paper with the blood spatter pattern was replaced each time a test firing was conducted with a new Styrofoam head.
Figure 7. 6 a, b, and c: Entrance wound (left), and the exit wound (middle) patterns produced in the Styrofoam head without the wig on top. The bag of Halloween blood placed in the middle of ballistic gelatin chunks in the hollowed-out head from the 9 mm hollow point bullets fired from three feet away. The right image illustrates how the bullet traveling through the Styrofoam head caused the side, as well as the back of the head to ‘blow out’.

Figure 7.7: An image of the back-spatter blood pattern of the Styrofoam head without the wig on top.
When the 9mm hollow point round was fired into the Styrofoam head, the head traveled backwards and pushed the white panel off the table and landed upside down. As shown in Figure 7.7, the large blood droplets from the back spatter trailed downward when the panel was upside down. The blood hit the panel and then was knocked on the floor upside down. During the time the panel was upside down, the blood flowed down. When the panel was set upright again (illustrated in Figure 7.7) the flowed appears to be flowing upward. The sides of the head exploded outward when the bullet traveled through the Styrofoam head, as shown in Figure 7.6 b and c. Without the wig on top of a Styrofoam head, more blood spattered on the white panel, as well as around the head. Some of the blood spattered on the previous blood spatter panel that was a result of the Styrofoam head with a wig on it being fired at. This caused the blood spatter pattern to be contaminated, as shown in Figure 7.8. A comparison of Figure 7.5 and 7.8 shows the before and after effect of the contamination of additional blood spatter.
Figure 7.8: An image of the blood spatter panel of the first Styrofoam head with the wig on top from Figure C.4, with the additional drops from the second Styrofoam head that were sprayed over a five-foot diameter. The green line separated the blood spatters that were produced from the Styrofoam head (right) and the Styrofoam head without a wig (left).

Even though the two Styrofoam heads were produced the same way, a blood bag surrounded by large chunks of ballistic gelatin, there was a significant number of differences observed between the Styrofoam heads. It was observed that the Styrofoam head without the wig on top produced larger blood spatter droplets and produced a larger spray diameter of blood spatter. There was also more tearing of the Styrofoam head without a wig than with a wig on based on the observations made in Figures 7.4 b and 7.6 b and c. Because there was more tearing of the Styrofoam head without the wig, more chunks of ballistic gelatin exited out of the hollowed-out head as shown in Figure 7.9 a and b. Once the bullet passed through this Styrofoam
head, it moved from its initial position to about three feet backwards and landed on its side. The bag of blood ruptured in the head and pooled out once the head landed in its final position, shown in Figure 7.9 a. In this image you can also see bits of gelatin that exited the Styrofoam head and landed on the table next to the final position of the Styrofoam head. Does hair play that significant of a role in alterations of blood spatter patterns and wound patterns, or is this observation strictly because the wig weighed more than the Styrofoam head and acted as an anchor?

Figure 7.9 a and b: Images of blood-pooling and ballistic gelatin chunks that exited out of the Styrofoam head without a wig on top. The blood spatter and ballistic chunks were found within a five-foot diameter of where the Styrofoam head’s final position was.
Figure 7.10 a, b, and c: Images of the Styrofoam head 3 (blood missed with liquid ballistic gelatin) after fired into with a 9mm hollow point round and from a distance of three feet.

Similar to the Styrofoam head without a wig, the effect of the bullet penetrating through the material caused the head to rupture, resulting in the observations shown in Figure 7.10 a, b, and c. The solidified ballistic gelatin with the blood mixed in with it blew apart into several chunks and exited the Styrofoam head through the large hole shown in Figure 7.10 c.
Based on the observations from Figures 7.5, 7.7, and 7.11, the Styrofoam head with the blood-mixed ballistic gelatin produced the smallest blood spatter when the 9 mm hollow point bullets were fired from a distance of three feet away. The purpose of using these different styled Styrofoam heads was to observe and compare the blood spatter patterns produced in living tissue. Many other variables could have been studied in this part of the research such as viewing other types of ‘brain’ simulants and other types of head simulants. These procedures could also be reproduced several times to observe if the blood spatter patterns would be consistent.

The results from this study are not comparable with injuries produced in human shots to the head from similar distances. The Styrofoam materials is not of similar density or toughness as human skull bones, which may be a reason why the Styrofoam heads exploded when the ammunition were fired into the media from a close distance of three feet away. The most accurate results based on the damage of the Styrofoam heads (entry and exit wound diameter) is the head with the wig on top. The wig held down the Styrofoam head which resulted in similar
back spatter patterns produced compared to human tissue, however further research would have to be conducted to verify this observation.
Conclusions

The purpose of this research was to accurately reconstruct various types of wound patterns in potential tissue simulants. These tissue simulants must be able to produce wound patterns like those that were produced in human tissue and skin without being expensive, and time consuming to manufacture. The materials that were used as potential tissue simulants throughout this project were ballistic gelatin, ballistic soap, Permagel, regular soap, porcine skin, white t-shirt attached to cardboard backing, clay, pressure-sensitive film, golden rod paper, and thermal-changing pigment. Most tissue simulants do not have the same physical properties that live human skin and tissue have; however, the materials may have some similar properties capable of producing similar type of wound patterns to human skin and tissue. Limited research has been conducted on types of materials that can be used as tissue simulants, and the reconstruction of various wound patterns for crime scene reconstruction. The reconstruction of wound patterns not only assists in determining the type of weapon that may have been used, it also can be used in court testimonies to help establish what might have occurred during the crime.

The findings from this project are as follows:

Ballistic gelatin was used as a potential tissue simulant in every section of this project, not just a potential tissue simulant for the ballistic sections. In the ballistic gelatin in the firearms section of this project, it was found that this material is an ideal tissue simulant for the reconstruction of gunshot wound patterns. The ballistic gelatin reacted similarly to how human tissue and skin would react if the same wound pattern was produced. A wider variety of variables such as shooting distance, bullet caliber and velocity, presence or absence of wig, type of
simulated brain (e.g. ballistic gelatin allowed to solidify with blood inside, vs. separate chunks of solidified gelatin surrounding a bag of blood vs. lone bag of blood in the center with no gelatin) should be explored with further research and compared to the findings from this project. It would be helpful to compare these results with actual criminal cases involving similar wound pattern and methods of production. The bite mark wound patterns that were produced in ballistic gelatin were also similar to wound patterns produced in human tissue and skin and provide a suitable test material for casting bite mark impressions. In a real case scenario, a perpetrator would unlikely be able to penetrate human skin and tissue as much as was produced in the tissue simulants. Additional research should be conducted to examine other variables such as pressure, bite angle, and other variables in the production of bite make wound patterns. It would be helpful if bite mark simulants could be compared to wounds from criminal cases.

Ballistic soap was also used as a potential tissue simulant throughout this reconstruction project. Due to its plastic-like elasticity, the ballistic soap produced temporal ballistic wound patterns, which assists in observing the amount of tissue damage that will result from a penetrating projectile bullet. Ballistic soap is an important material for observing the temporal wound cavity in ballistic wounds, however it is not intended to strictly duplicate the wound produced in living tissue as it would resume its previous shape. As such, the ballistic soap can give a permanent representation of the type of temporary cavity that might have been found in human tissue under maximum velocity and projectile pressure during periods of maximum tissue displacement.

Ballistic soap was also an ideal tissue simulant used in this project for the reconstruction of blunt force wound patterns. A very thin indentation pattern of the overall glass bottle, as well as the distinctive oppression glass patterns were observed.
Permagel had thermal stability but otherwise, it was a difficult material to work with and was found in this project, not to be an ideal tissue simulant for the reconstruction of any type of wound produced. Permagel did have wound patterns similar with those produced in the ballistic gelatin when the round nose bullets were fired into the materials in the ballistics study; however, there was no tearing patterns produced around the entrance nor exit wounds, which would occur in a wound pattern on human skin and tissue at close range or contact. It is unclear why this is so, especially when the general trend is that there is more tearing patterns produced from a fired hollow point round. The physical properties of the Permagel, such as the elasticity or density of the material is different from those of ballistic gelatin, causing less tearing to occur.

Because there is limited research conducted on the analysis of slice wounds, it is unknown if the Permagel would be a suitable a tissue simulant for the reconstruction of slice wounds. The Permagel material made producing chop wounds very difficult and the way the patterns were produced would be unrealistic in a crime scene situation.

Although regular soap was only initially added into this project as a curiosity in the wound patterns produced from fired projectile bullets, it was a material that was used throughout the entire project to observe the wound patterns that this material could produce. It was found that regular soap did not produce wound patterns similar to those produced in ballistic soap likely because of regular soap’s different physical properties. The primary difference between the regular soap and the ballistic soap is the addition of the gelatin powder in the ballistic soap. This addition of this material gives the media more elastic properties similar to human tissue than regular soap.

Clay was a material that was used in the reconstruction of all wound patterns produced in this project except for gunshot wounds. There was not enough of the clay material available to
make blocks large enough for the ballistics section. Clay was found to be an ideal tissue simulant for the blunt force wound patterns in this study. The clay material produced blunt force wound patterns similar to the wound patterns produced in the ballistic soap. The clay material was also an ideal tissue simulant for the reconstruction of sharp force wound patterns. In previous research, clay was used as a tissue simulant to accurately produce incised wound patterns, but chop wound patterns were not investigated using this media (Bleetman, et al, 2003). Based on the findings of this project, there was some striation pattern detail produced in the clay material, similar to wound patterns that would most likely be produced in human skin and tissue. As previously mentioned, there has not been many chop wounds observed or researched.

Golden rod paper was a material used as a potential tissue simulant in this project due to its potential electrical properties mentioned in literature. When the Taser was placed on the golden rod paper and the electrical arc made contact with the material. It was found that no electrical wound patterns were produced on the golden rod paper.

Thermal-changing pigment was a material added to the list of potential tissue simulants in this project because electrical wound patterns were unable to be produced in any of the other materials. The electrical arc of the Taser was placed directly on the plastic bag that enclosed the thermal-changing pigment, resulting in a small color change in the pigment powder around the area that was touched by the electrical arch. Future research could investigate mixing the thermal-changing pigment in ballistic gelatin and observing if a wound pattern is produced. Due to time restraint and lack of ballistic gelatin powder, this could not be tested in this study.

The bloodstain patterns that were produced from the Styrofoam heads all differed due to the addition of a wig or a different brain simulant procedure. It was recommended that the back spatter that was similar to human tissue was the Styrofoam head with the wig. The wig weighed
down the head, allowing the bullet to pass through the head without moving the head significantly.

The reconstruction of wound patterns in tissue simulants has not been extensively researched, however it is a very important topic in the forensic field for the purpose of crime scene reconstruction. Research should continue to be conducted because there are many different variables that effect the appearance of a wound pattern.
All References


Appendix I

Tissue Simulant Procedures:

Figure A I.1: Chemical structure of gelatin.

Image obtained from the Internet: Google Images

Ballistic gelatin preparation (10% ordnance gelatin) based on FBI procedure:


Gelatin powder was dissolved in 6L of warm tap water and heated on a hot plate until the powder is fully dissolved. Three liters of tap water was added to the mixture and mixed until the solution was homogeneous. The temperature of the solution was made steady at 49-69°C as to not burn the gelatin powder. Because 10% ordnance gelatin was made, about 1000g of gelatin powder was used with a total of 9 L of tap water. Occasionally foam or bubbles would be observed if the solution was not mixed very slowly and cinnamon tree oil or ground cinnamon was added to reduce the appearance of the bubbles. After all of the gelatin powder was dissolved
in solution, it was poured into a plastic mold and left to sit at room temperature for about 4 hours to slowly cool. The container of liquid gelatin is then placed in a cold room or refrigerator with a temperature of 4°C to cool the gelatin to a solid structure for at least 48 hours, as shown in Figure A I.2. The solid ballistic gelatin is removed from the mold and wrapped in cellophane and stored in 4°C temperature until use.

This procedure was used to produce 99% of the ballistic gelatin used in this project.

Figure A I.2: Image of ballistic gelatin after solidification in a plastic mold

**Ballistic gelatin preparation (10% ordnance gelatin) based on Fackler and Malinowski procedure:**


Gelatin powder was mixed with 9L of cold tap water with a temperature of 7-10°C and mixed until the powder was completely dissolved. This step may be challenging as the powder instantly enlarges and solidifies due to the low temperature of the water. Because 10% ordnance
gelatin was made, about 1000g of gelatin powder was used with a total of 9 L of tap water. The mixture was placed in a cold storage room or refrigerator at 4°C for 2 hours. The solidified mixture is cut into smaller chunks and placed in a large pot to slowly melt and become homogeneous on a hot plate. The temperature of the solution was maintained at 40°C to ensure the gelatin powder did not burn. Occasionally foam or bubbles would be observed if the solution was not mixed very slowly and cinnamon tree oil or ground cinnamon was added to reduce the appearance of the bubbles. Once the gelatin was fully melted, the solution was placed in a plastic mold and placed in a cold storage room at 4°C for 24 hours. The solid ballistic gelatin was removed from the mold and wrapped in cellophane and stored in 4°C temperature until use, as shown in Figure A I.3.

Figure A I.3: Image of solidified ballistic gelatin wrapped in cellophane

Helpful tips and observations for ballistic gelatin:

For optimal ballistic gelatin preparation, the entire amount of powder should be mixed with 1 or 2L of hot tap water and heated until the powder is fully dissolved. The mixture can then
be diluted to make a total of 9L of liquid gelatin before being placed into a container. This process also reduces the chance of bubble or foam forming. If cold tap water is added to the gelatin powder, then the powder will solidify too quickly and large chunks of semi-solidified gelatin will be difficult to melt down and fashion into smaller chunks. It is very time consuming if 9L of tap water is heated until the optimal temperature is reached and then the gelatin powder is added. The gelatin powder with water must be stirred frequently to ensure the mixture is not burning or overheating on the bottom of the stockpot. On average, the preparation of 9L liquid gelatin for the formation of gelatin blocks is about 1 to 2 hours per block.

It is important to note that the liquid gelatin should be placed in a plastic mold container rather than a stainless steel metal mold. When the gelatin solidified, the sides of the gelatin were stuck to the metal container and ended up coming out of the mold in pieces, rather than one block. It is also important to note not to line the mold containers with plastic wrap before placing the liquid gelatin in the containers. The heat from the liquid gelatin melts the plastic wrap and ends up solidifying within the middle of the gelatin, both for the metal and plastic containers. It was found in the literature that the gelatin will not stick to the sides of the metal container if silicone (WD 40) is sprayed on the inside of the metal mold container before the liquid gelatin is added (Jussila, et al, 2004). This however was not tested and 9L plastic containers with lids were used throughout the formation of ballistic gelatin and soap. After solidification of the gelatin, a bread knife or a spatula should be used to slightly be moved around the edges and sides of the container to loosen the gelatin from the mold. The block of gelatin will slip easily out of the mold once flipped upside down, where it can then be wrapped in plastic wrap and taped to ensure no air can come into contact with the gelatin.
Mold was a major problem when working with the gelatin as well as the storage conditions of the gelatin before and after shooting the simulant. The cold room that was being utilized would not always remain at 4°C and the humidity in the room would also vary. This would lead to the slight melting of the gelatin, resulting in a “snot-like” goo around the edges of the gelatin as well as the shelving the gelatin was stored on if the gelatin was not properly wrapped. For optimal gelatin stiffness, make sure the blocks are placed in a reliable cold room with low humidity and temperature of about 4°C.

Re-melting the ballistic gelatin after shooting is not recommended. Out of the 6 ballistic gelatin blocks that were re-melted, only two blocks re-solidified. It is important to note that the blocks that did re-solidify were not as stable or stiff as the first time prepared. It is also important to note that they were stored in the cold room that was determined to be have variable swings in humidity and temperature and therefore could have had an effect on the re-solidification of the gelatin blocks. The other four blocks that were melted down did not solidify at all and were determined to have had bacteria on the block before re-melting. Further studies should be performed to determine under what optimum conditions if ballistic gelatin can be re-melted and solidified.
Ballistic soap preparation:

Glycerin soap was completely melted using a hot plate and a large pot. While the glycerin was melting, gelatin powder was mixed with warm tap water and mixed together. The liquid glycerin was placed in the gelatin mixture and mixed. The solution was placed in a cold storage room or refrigerator at 4°C for 2 hours. About 2 lbs (907 g) of glycerin was mixed with 461.3 g of gelatin powder and 6 L of tap water. The solidified solution was cut into large chunks and placed in a large pot to slowly melt and homogenize. Occasionally foam or bubbles would be observed if the solution was not mixed very slowly and cinnamon tree oil or ground cinnamon was added to reduce the appearance of the bubbles. The melted solution was poured into a plastic mold and placed in a cold storage room at 4°C for 24 hours. The solid ballistic soap was removed from the mold and wrapped in cellophane and stored in 4°C temperature until use, as shown in Figure A 1.4.

Figure A 1.4: Image of a solidified block of ballistic soap

Helpful tips and observations for ballistic soap:
Important to note that bubbles/foam forms more readily than from ballistic gelatin and more time consuming to make than ballistic gelatin. Also it was found that forming ballistic block was easier to mix than for ballistic gelatin. I believe this was because the heat from the melted glycerin, as well as using hot tap water made it easier to mix the gelatin powder into the water than for ballistic gelatin. This could also be due to the fact that there was less gelatin powder mixed with water.

Glycerin is an ingredient that gives media, such as ballistic gelatin and ballistic soap, different physical properties that ballistic gelatin. As shown in Figure A I. 5, the glycine molecule is not very large, however if an abundance of these molecules were attached to the gelatin molecule, shown in Figure A I. 1, then the overall compound would not be able to move easily. This result is the reason why ballistic soap has a plastic-like elasticity rather than a similar elasticity to ballistic gelatin and living tissue, as previously mentioned in Chapter Two.

Glycerin soap base ingredients:

Glycerin, prop glycol, sodium stearate, sodium laurate sulfate, sorbitol, coconut oil, sodium myristate, trimethanolamine, sodium laurate, sodium cocoate, water

Gelatin powder was tared using Mettler PE 4000 scale

![Glycerin chemical structure](Image obtained from the Internet: Google Images)
Regular soap block preparation:

Individual bars of Dial soap were purchased from a retail business (Dollar Tree) and were shredded with a kitchen grater. The shredded bar soap was placed in a stockpot and heated until a homogenous mixture was produced. Once the heat was initiated to the soap, it started to burn on the bottom of the stockpot and so small amounts of tap water was added to the mixture. This type of soap was difficult to melt down, which is the reason why the block of regular soap did not appear to look homogenous. Once the mixture was melted, the semi-solid was poured into a plastic mold and allowed to harden.

*Figure A I. 6*: An image of the type of soap bar used to produce the regular soap block

*Figure A I. 7*: An image of the solidified regular soap block
Appendix II

Types of firearms used throughout ballistics study:

Glock 17 gen 4

Used to fire 9mm round nose and hollow point rounds

Table A II.1: Glock 17 gen 4 specs

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<td>Overall length of gun</td>
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<tr>
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<td>Safety type</td>
<td>Trigger block</td>
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<tr>
<td>Type of firearm</td>
<td>Semi-automatic pistol</td>
</tr>
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</table>

Shooter: Cliff Schlemmer; experience using handguns for 6 years, however has been using other types of firearms most of his life. He was a range instructor when the test firings were performed.

Figure A II.1: Image and dimension details of a Glock 17 gen 4 firearm
Image obtained from the Internet: Googles Images
Glock model 22

Used to fire .40 round nose and hollow point rounds

Table A II.2: Glock 22 specs

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Shooter: Cliff Schlemmer

Figure A II.2: Image and dimension details of Glock 22 firearm
Image obtained from the Internet: Google Images
Glock model 21

Used to fire .45 round nose and hollow point rounds

*Table A II.3: Glock 21 specs*

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Shooter: Cliff Schlemmer

*Figure A II.3: Image and dimension details of a Glock mode 21 firearm*

Image obtained from the Internet: Google Images
9mm Smith and Wesson 5946

Used to fire 9mm round nose and hollow point bullets

Table A II.4: 9mm Smith and Wesson 5946 specs

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Shooter: Retired Det. M. Byrnes; on the New York police force for 27 years

Figure A II.4: Image of 9mm Smith and Wesson 5946 firearm
Image obtained from the Internet: Google Images
Colt Officers ACP

Used to fire .45 round nose and hollow point rounds

*Table A II.5: Colt Officers ACP specs*

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Shooter: Retired Det. Byrnes

*Figure A II.5: An image of a Colt Officers ACP Firearm*

Image obtained from the Internet: Google Images
Appendix III

Properties and history of Ammunition used in Master’s project:

**9mm Luger:** also known as 9 x 19 mm Parabellum or 9 mm Luger +P

Introduced in 1902 by Luger Automatic Pistol, and adopted by German Navy in 1904, and then the German Army in 1908. After few years the ammunition was first choice for every non-communist military force. This type of ammunition became the world’s most popular and widely used military handgun and submachine gun cartridge. This type of ammunition can be used in handguns such as Colts, Smith and Wesson, and Ruger. It is widely used and popular due to its good performance. American-made Smith & Wesson and Colt handguns were not chambered for the use of this type of ammunition until 1954 when Smith and Wesson introduced its Model 39 semi-automatic and Colts brought out its light-weight Commander 9 mm Luger in 1951.

The disadvantage of this type of ammunition is that it lacks stopping power as a defense cartridge. The .45 auto has been demonstrated to have superior stopping power. The addition of jacketed hollow point loads have improved stopping power in 10% ordnance gelatin (Barnes, 2019).

**9mm Luger round nose bullets**

Manufacturer: Precision made cartridges (PMC) ammunition bronze, made in R. O. Korea

http://pmcammo.com/

Weight in grains: 115 grains
Type: full metal jacket
Type of firing: centerfire
Velocity: 1150 ft/second  energy: 338 ft-lbs.
Appearance: Lead-core (non-magnetic), copper jacket, brass casing
Other features: Little to no expansion, Boxer primers

*Figure A III.1:* 9 mm Luger round nose cartridges from PMC Bronze Ammunition

**9mm Luger Hollow point bullets**

Manufacturer: Extreme Terminal Performance (XTP) Hornady American Gunner, made in US
https://www.hornady.com/bullets/xtp#!/

Weight in grains: 115 grains
Type: Full metal jacket
Type of firing: Centerfire
Velocity: 1155 ft/s  energy: 341 ft-lbs.
Appearance: lead core, brass casing, Boxer primer
.40 Smith and Wesson:

The cartridge was developed as an ammunition combination between Winchester and Smith and Wesson. The development and standardization of the cartridge was of primary concern for law enforcement. After development, the FBI switched to this ammunition from 10 mm automatic. It was found that the .40 S & W could provide the same stopping power as the 10 mm automatic but used a shorter cartridge. This allowed for greater accuracy and allowed for a smaller, more comfortable grip frame for the handguns. High peak pressure (due to compact package) and a short barrel means that there is going to be an increase in noise and muzzle blast by using the .40 caliber (Barnes, 2019).

**40 Smith and Wesson round nose bullets**

Manufacturer: Precision made cartridges (PMC) ammunition bronze, made in R. O. Korea

http://pmcammo.com/

Weight in grains: 180 grains
Type: Full metal jacket

Type of firing: centerfire

Velocity: 985 ft/s   energy: 388 ft-lbs.

Appearance: brass casing with boxer primers, copper or brass appearing bullet with a flat top, lead core with copper jacket

Figure A III.3: .40 caliber Smith and Wesson round nose cartridges from PMC Bronze Ammunition

40 Smith and Wesson hollow point bullets

Manufacturer: Extreme Terminal Performance (XTP) Hornady American Gunner, made in US

https://www.hornady.com/bullets/xtp#1/

Weight in grains: 180 grains

Type: Full metal jacket

Velocity: 950 ft/s   energy: 361 ft-lbs.

Appearance: Boxer primer, brass casing, lead core, point is narrower than round nose bullet but more hollow than of a 45 auto hollow point
**Figure A III.4**: .40 caliber Smith and Wesson hollow point cartridges from XTP Hornady

**.40 Smith and Wesson hollow point bullet (law enforcement issued)**

https://www.federalpremium.com/

Manufacturer: Federal Ammunition

Weight in grains: 180 grains

Type: Jacketed Hollow point

Velocity: 1010 ft/second energy: 408 ft-lbs.

Appearance: nickel-plated brass casings, Boxer primer, lead core, copper jacketed
.40 Smith and Wesson hollow point law enforcement issued cartridges

.45 Automatic rimmed: also known .45 auto rim

Developed during WWI for Colts and Smith and Wesson revolvers, however required a half-moon clip that held three-rounds, to support the rimless cartridges. The rimless cartridges were then required to be ejected by hand, shaking them out of the cylinder or poking the cases out individually. In 1920 Peters Cartridge Company introduced rimmed .45 with lead loaded bullets for the M 1917 revolver to reduce rifling wear. Other features with these types of handguns included oversized cylinder throats for mitigating chamber pressure. This is because there is a significant amount of gas that escapes before the peak chamber pressure is reached (Barnes, 2019)

.45 Auto round nose bullets

Manufacturer: Precision made cartridges (PMC) ammunition bronze, made in R. O. Korea

http://pmcammo.com/

Weight in grains: 230 grains

Type: Full metal jacket

Type of firing: centerfire
Velocity: 830 ft/second  energy: 352 ft-lbs.

Appearance: Copper appearing bullet with bronze cartridge, lead core enclosed by a string metal jacket

Other features: non-expanding and deep penetrating, used in all types of semi-auto’s, use bullseye powder

Figure A III.6: .45 caliber auto round nose cartridges from PMC Bronze Ammunition

.45 Auto hollow point bullets

Manufacturer: Extreme Terminal Performance (XTP) Hornady American Gunner, made in US

https://www.hornady.com/bullets/xtp#!/

Weight in grains: 185 grains

Type:

Type of firing: Centerfire

Velocity: 970 ft/s  energy: 386 ft-lbs.

Appearance: brass casing with lead core, flat point with hollowed, brass cartridge
Figure A III.7: .45 caliber auto hollow point cartridges from XTP Hornady
Appendix IIII

Worksheets used throughout firearm experiments

Styrofoam Heads

Head number: ________________

Distance from shooter to head: ____________________________

Distance from head to witness panels : __________________________

Ammunition used: ____________________

Gun used: ________________________

Number of shots fired: ________________________

Was a blood pattern present? ______________

What is the general blood pattern? ______________

Greatest distance from head to blood stain: ______________

Was the head still in-tact? ______________

Length of entry wound: ____________  Length of exit wound: ____________

Height of entry wound: ____________  Height of exit wound: ____________
Distance between front witness pattern and target: ______________________________
Distance between rear witness pattern and target: ______________________________
Shooting Information

Experiment: ____________________________________________________________

Type of simulant used:  Permagel       Ballistic Gelatin       Ballistic soap
Number of simulants used in experiment: ____________

Gelatin Number: ____________

Type of ammunition used: _________________
Different types of ammunition used: ________________________________
Gun used: ___________________________

Number of total shots fired in experiment: ____________________________

Camera picture range: ____________________________

Distance from shooter to simulant: ____________________________
Different distances used in experiment: ____________________________
Number of shots per distance: ____________________________
Dimensions of simulant blocks: ____________________________

Pig skin used? ____________
Any tattooing or stippling/ marks in skin? ______________________________

**Shot 1:**

Length of entry wound: ______  Length of exit wound: ______

Height of entry wound: ______  Height of exit wound: ______

Length of bullet penetration in simulant ____________________________

Did bullet remain in-tact or fragment? ______________

Number of fragmentations: __________

Distance from bullet fragments to main bullet: ______________________

**Shot 2:**

Length of entry wound: ______  Length of exit wound: ______

Height of entry wound: ______  Height of exit wound: ______

Length of bullet penetration in simulant ____________________________

Did bullet remain in-tact or fragment? ______________

Number of fragmentations: __________

Distance from bullet fragments to main bullet: ______________________
Shot 3:

Length of entry wound: _______  
Length of exit wound: _______

Height of entry wound: _______  
Height of exit wound: _______

Length of bullet penetration in simulant_____________________________

Did bullet remain in-tact or fragment?______________

Number of fragmentations:___________

Distance from bullet fragments to main bullet:_____________________

Shot 4:

Length of entry wound: _______  
Length of exit wound: _______

Height of entry wound: _______  
Height of exit wound: _______

Length of bullet penetration in simulant_____________________________

Did bullet remain in-tact or fragment?______________

Number of fragmentations:___________

Distance from bullet fragments to main bullet:_____________________