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Open Fire: The Expansion of 9mm Hollow Point Bullets in Relation to Tissue Thickness

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This thesis has been presented to and accepted by the office of Graduate Studies, John Jay College of Criminal Justice in partial fulfillment of the requirements for the degree of Master of Science in Forensic Science.

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Abstract

Bullets can be broadly differentiated into jacketed and unjacketed groups. Jacketed ammunition can be further broken down based on the bullet's design, one of which is hollow points. This research examines a representative brand of jacketed hollow point bullets used in a common caliber cartridge, the 9mm Luger. A jacketed hollow point bullet is designed to expand when it encounters a viscous medium such as tissue. This experiment simulated tissue using ballistic gelatin and simulated skin using a chamois overlay. As a positive and negative control, a series of bullets were fired into a full-size block of gelatin to achieve complete expansion and into just cotton waste to resist expansion. There are six segments that compose the tip and ogive of the hollow point bullet used in these tests. The length of the bullet was measured, as well as the distance between the opposing petals of each bullet, resulting in three width measurements per bullet. There were five bullets fired for gelatin thicknesses of 7.6 cm, 5.1 cm, 3.8 cm, 2.5 cm, and 1.3 cm, as well as for the negative and positive controls. The average distances of the expanded petals decreased as the thickness of the gelatin decreased. Velocity data was collected from the muzzle of the firearm to check for consistent impact velocity as that is a parameter that affects the expansion of hollow points. This research is intended to provide an understanding of hollow point behavior, which is beneficial in crime scene reconstructions involving shootings.

Introduction

Crime scene reconstructions are relied on by law enforcement and lawyers to provide accurate sequences of events using only physical evidence. Analysis is done to provide details that are more reliable than witness statements and testimonies. Evidence such as DNA is often highly regarded because of its ability to place individual people at scenes, but to understand what occurred and how requires examining other types of evidence.

Firearms analysis is a section of forensic science that focuses on firearms and the components of a cartridge: cartridge case, projectile, powder, and primer. There are characteristics of these types of evidence that can be classified or even individualized. Firearms and bullets can also fall under the field of ballistics, which is the study of projectiles in motion. Ballistics examination can determine where a bullet has traveled, if it made contact with any substrates, and how the firearm was positioned when fired. There is an abundance of ammunition types, which were created for different purposes over the years. At crime scenes, ammunition like full metal jackets, hollow points, and soft points are most common because they are cheaper and more popular. It is harder to trace popular ammunition unless you have the batch number linked to those cartridges.

Hollow point bullets are unique compared to other bullet types because of their engineered expansive properties. When contacting a viscous substrate, the petals at the nose of the bullet spread apart in a stellate pattern. This design is to cause more damage by transferring more of the bullet's energy into its target. These are utilized by law enforcement as department issued ammunition and can also be purchased by civilians depending on their state laws. The military, though, does not utilize expanding ammunition because it would be a violation of the 1899 Hague Declaration as they are considered too damaging and inhumane to be used in combat (Abbenhuis et al. 2022). Hollow points have become popular because of their ability to incapacitate the target, which makes them common at crime scenes. Any interactions between the bullet and the skin, tissue, and bone of an organism, termed wound ballistics, can be studied to better understand the behavior of hollow point bullets. This is helpful for crime scene reconstructions when these bullets are recovered at a crime scene alongside an injured or deceased party. This research is intended to supplement past studies on hollow point bullet behavior and understand its wound ballistics to aid in crime scene reconstructions.

Literature Review

Shooting Reconstructions

Crime scene reconstructions rely on the scientific analysis of physical evidence to provide proof of a sequence of events, especially in the absence of reliable eyewitnesses. Shooting scenes specifically involve a projectile or multiple projectiles, often resulting in injuries and deaths. Reconstructions of these scenes are determined using the behavior, chemistry, and physics of firearms and ammunition (Haag, 2006). Studies have been done regarding ballistics and firearms analysis to better the realm of shooting reconstructions.

Trajectory

Bullet trajectory is the pathway that a bullet follows after being fired. It is calculated by examining impact marks, which is where the bullet strikes or penetrates a surface. The trajectory can be traced back to the location of the muzzle of a firearm, as well as its positioning (Mattijssen & Kerkhoff, 2016; Nishshanka et al. 2023). There are many methods used to determine the bullet's trajectory, and one should be chosen depending on the angle of impact and the substrate impacted. One of the methods is called the probing method, which involves inserting a rod through the bullet hole to visualize the path of the bullet (Liscio & Park, 2021). This works best when there are distinctly separate entry and exit holes through a thicker substrate (e.g. a wall). The lead-in method focuses on the angle of the initial impact of the bullet (lead-in area). A rod is placed so one end rests along the lead-in area and an inclinometer is used to determine the angle of impact. The ellipse method uses trigonometric ratios based on the angle of the bullet hole, but often has greater errors than the previous two methods (Liscio & Imran, 2020).

Ricochet

If multiple impact marks are present, this may indicate ricochets, where the bullet collided with a surface without passing through it (Nishshanka et al. 2020). Ricochets depend on the angle of the bullet relative to the surface it is striking, type of bullet, velocity of the bullet at impact, and the substrate material. These parameters can be determined post-shooting based on the characteristics of the primary impact marks (ricochet) and secondary impact marks (bullet holes).

Distance Determination

The distance from the muzzle of the firearm to bullet holes can be calculated based on the pattern of gunshot residue (Pyl et al. 2019) and even the characteristics of the bullet hole itself (Lee, 2020). There are multiple tests that can be done to visualize the gunshot residue surrounding bullet holes, which can then be measured to determine the distance from the muzzle. One of these tests is the Modified Greiss Test (MGT), which is a sequence of tests done which develops burned residue with an orange color change (Berger et al. 2019). The Total Nitrite Pattern Visualization (TPV) method begins with alkaline hydrolysis followed by the same reactions executed with MGT (Glattstein et al. 2000). This test develops unburned residue with an orange color change. The method chosen depends on the substrate the bullet penetrates because of the difference in affinity of the adhesion of residues.

These components in conjunction with identification of bullets, cartridge casings, and firearms can be used to build a reconstruction of events. Usually, there is evidence at the scene besides impact marks that indicate a shooting occurred. Fired bullets, cartridge casings, and even the firearm itself can be collected and analyzed to determine their characteristics. The firearm is often not present at the scene, but the bullets and cartridge casings can indicate the type of firearm used based on breech face markings, striations, and outward appearance.

Bullets and Cartridge Casings

A cartridge consists of several components (see Figure 1), that after being fired contain information that is useful to firearms analysis. All are useful in firearms analysis and shooting reconstructions, but in the absence of a firearm, the bullet and cartridge casing provide the most information.

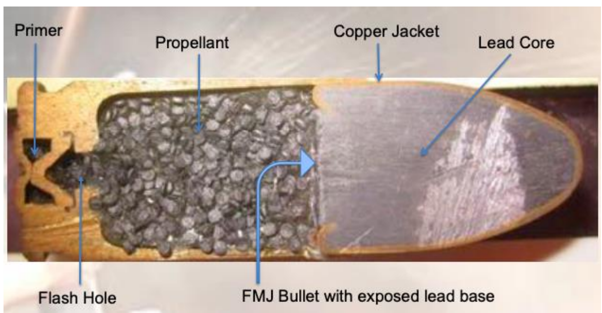

Figure 1. Cross-section of a full metal jacket cartridge displaying some key components of ammunition.

The fired bullet may provide individualizing characteristics that trace back to a single firearm. Striations are lines that mark the bullet as it passes through the barrel of a firearm, unique because they are formed by the manufacturing process and repeated use. Fired bullets recovered at a crime scene can be compared to test fires from a suspected firearm, assuming it is recovered, using their striations, which can be viewed simultaneously using a comparison microscope (De Kinder & Bonfanti, 1999).

The cartridge case, whether center fire or rim fire, is also marked by the firearm from which it was discharged. These markings include breechface impressions, especially on the softer metal of the primer. The primer will also be the location of the firing pin impression, a useful mark that can be used to associate cartridge cases to one another, or if available, to a specific firearm. The easily identifiable characteristics of cartridge casings and bullets, such as class, color, and caliber are often varied among manufacturers and types of firearms.

Hollow Point Bullets

One class of bullets termed for the cavity at the tip of the nose is hollow point bullets. The nose is composed of segments, commonly called petals, which are designed to expand in a controlled manner when it comes into contact with a viscous medium such as tissue or water. The difference between a bullet with no expansion and a bullet with full expansion is shown in Figure 2.

Figure 2. Side by side comparison of two fired hollow point bullets with no expansion (left) and full expansion (right).

Hollow points are intended to inflict more damage by transferring more of its kinetic energy into its target instead of piercing through and possibly causing collateral damage. The complete expansion of hollow point bullets undergoes a four-step process when encountering a substrate described by Jiang et al. (2021). Stage one is the bullet passing into the gelatin from air, resulting in a big change in density and resistance. As the petals of the bullet cut into the gelatin, they began to expand. Stage two is the continued expansion of the petals and the decrease in velocity of the bullet. Stage three is when the bullet reaches maximum expansion. Stage four is the contraction and then settling of the petals into permanent deformation. Each of these stages occurs at different times between different hollow point bullets depending on their characteristics and any external factors, like the type of firearm or target substrate.

Wound Ballistics

Ballistics is a field of applied physics that studies the motion of a projectile in flight. It can be broken down into three sections: internal ballistics, external ballistics, and terminal ballistics (Carlucci & Jacobson, 2018). Using bullets as an example, internal ballistics is the inner workings of the components of the firearm at discharge, external ballistics is the motion of the bullet between the muzzle of the firearm and its target, and terminal ballistics is the motion of the bullet between penetrating a target and coming to rest. Wound ballistics is a subsection of terminal ballistics involving the physics of the bullet when inflicting damage to either animal or human tissue (Coupland et al. 2011). Hollow point bullets are created to expand when penetrating a viscous substrate, such as tissue, but there are internal and external factors that can affect this expansion.

Manufacturer

The manufacturer of the hollow point ammunition can affect its expansion performance by altering the construction of the cartridge, which includes alloys, coatings, and calibers. In the 1990s, Winchester created a hollow point bullet that was intended to be used by law enforcement following a series of FBI Firearms Training tests (McCormick et al. 1996). The results found that the current hollow point ammunition was not up to their standards, thus the Black Talon ammunition was created. Named for its black oxide coating and sharp petals, these hollow points were designed to pass through thick substrates and still penetrate any human or animal tissue with sufficient kinetic energy for expansion. These cartridges specifically have since been discontinued because of social pressures regarding it as too damaging, but similar ammunition is still on the market. Not all hollow points are designed like these, but there are different ways that manufacturers change the construction of the cartridges to alter their expansive properties.

Impact Velocity and Kinetic Energy

Kinetic energy and velocity relate by the equation $KE = \frac{1}{2} mv^2$. The impact velocity correlates to the amount of kinetic energy at the initial moment in terminal ballistics. When impact velocity is compared with the exit velocity, the result is the amount of energy transferred to the target. Non-expanding bullets and full metal jackets tend to have a minimal amount of kinetic energy transfer compared to hollow points, which transfer as much kinetic energy as possible (DiMaio, 2016). In a study by Schyma et al. (2019), they compared the transfer of kinetic energy to ballistic gelatin between full metal jacket and hollow point ammunition using the impact and exit velocity. The full metal jackets averaged between 16% - 25% of kinetic energy deposited to the gelatin, while the hollow points averaged between 80% - 93% of kinetic energy deposited to the gelatin. In regards of expansion, previous research has repeatedly proven that as the kinetic energy of the hollow point increases, expansion increases up to a certain threshold before plateauing when full expansion has been achieved (Werner et al. 2017; Bresson et al. 2012; Jiang et al. 2021). When the bullet travels below a point termed critical velocity, there will not be complete expansion because of the lack of sufficient hydraulic pressure from the substrate to force the petals to open properly.

Substrate Thickness

There are few studies that focus entirely on substrate thickness in relation to hollow point expansion. It has, instead, been included as small, side experiments when investigating other factors that influence expansion. There have been claims that full expansion occurs at 3 centimeters gelatin thickness at around 1500 feet per second (Schyma et al. 2019), while there have been other claims that full expansion occurs at 5 centimeters gelatin thickness without noting the impact velocity (Bresson et al. 2012). The maximum substrate thickness can technically change as the impact velocity changes. It has already been proven that velocity, and thus kinetic energy, can affect expansion, so that will not change because there is a change in the thickness.

There is controversy amongst professionals in the criminal justice field of admitting and testifying to reconstructions in the court of law. There are critics that claim shooting scene reconstructions are based on “untried and unproven scientific principles” (Haag, 2006, p. 250). It is the accumulation of a multitude of scientific principles, though, that forms the basis of these reconstructions. The research discussed in this paper involves individually observing and determining expansion of hollow point bullets. Combining previous research on shooting distance, substrate makeup, brand of ammunition, and size of ammunition with novel research on change in expansion with change in tissue thickness provides an understanding of hollow point behavior.

Methods and Materials

The substrate was Permagel® ballistic gelatin covered in chamois, which simulates tissue and skin, respectively. Prior to sample collection, the full gelatin block was calibrated by using a Daisy Rogers .177 caliber BB gun to fire five rounds of Copperhead BBs equidistant to one another along the short side. Since heat affects the gelatin's performance, the temperature was found using an outdoor thermometer, which ranged 26-30°C. The distances the BBs traveled into the gelatin were measured and compared to ensure they were similar (Table 1).

Round	Distance Traveled into Gelatin
BB 1	3.9 cm
BB 2	3.3 cm
BB 3	4.0 cm
BB 4	4.4 cm
BB 5	4.6 cm

Table 1. The distances the BBs traveled into the gelatin in centimeters.

The firearm used in this experiment was a Ruger PC-9 (Police Carbine 9mm) semiautomatic rifle in 9mmL caliber [Figure 3.], which was secured in a mechanical rest to keep the shooting height and distance consistent.

Figure 3. Ruger PC-9 in its mechanical rest.

The ammunition was 9mm LUGER Fiocchi 147 grain centerfire jacketed hollow points with an average muzzle velocity of 975 feet per second [Figure 4.]. All cartridges were loaded directly into the chamber and fired individually for safety purposes.

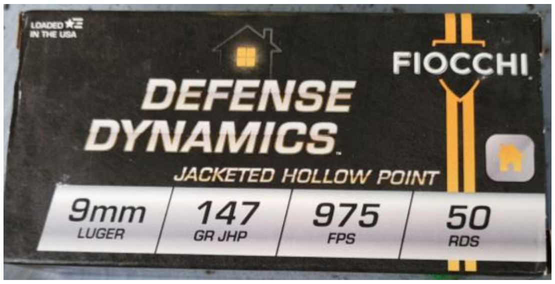

Figure 4. Jacketed hollow point ammunition.

A Competition Electronics Prochrono® chronograph was set up on a tripod between the muzzle of the firearm and the table where the substrate would rest [Figure 5.]. This was to capture the impact velocity of the fired bullets for consistency and to ensure the velocity was not fluctuating severely between rounds. Two strips of infrared LED arrays were set up above the chronograph because changes in ambient lighting will affect the sensitivity of the sensors. All impact velocities were measured in feet per second. On the other side of the substrate were cardboard boxes stuffed with cotton material to catch the bullets.

Figure 5. Set up for experiment with firearm in its rest, chronograph with infrared strips, and recovery boxes.

Prior to shooting into the ballistic gelatin, five bullets were fired directly into the cotton filled boxes to demonstrate no secondary expansion would occur when entering the recovery system. The full gelatin block was set up between the chronograph and the recovery system with the short side facing the muzzle of the firearm. A Wheeler Professional® Laser Bore Sighter was placed at the muzzle to show where the bullet would penetrate the gelatin. Five cartridges were fired along the center horizontal plane equidistantly with breaks between each to record the impact velocity and search by hand to recover the bullet. The cotton material was repacked to avoid creating a tunnel where the bullets could easily pass through. When all samples were completed, the gelatin block was melted and reconstituted to clear the paths forged by the bullets. The gelatin was sliced along the short axis into five different widths: 7.6 centimeters, 5.1 centimeters, 3.8 centimeters, 2.5 centimeters, and 1.3 centimeters. Each gelatin slice underwent the same procedure as the full gelatin block to collect an array of samples for different thicknesses. The expansion of the recovered bullets was measured, in millimeters, using a Pittsburgh® 6" caliper [Figure 6.].

Figure 6. Pittsburgh® 6-inch caliper

The six petals that compose the tip and ogive of the hollow point bullet were used as the measuring points. The distance between all the opposing petals of each bullet at their widest points were measured, as shown in Figure 7., resulting in three measurements per bullet.

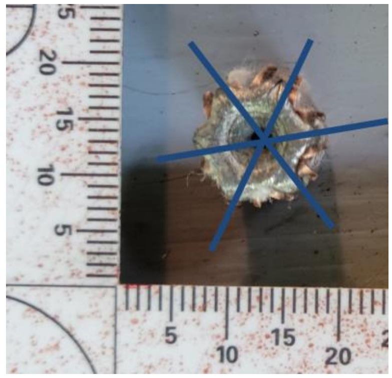

Figure 7. Expanded hollow point bullet with lines indicating the width measurements.

These measurements comprised the widths of the bullets. The length of the bullets at the longest points were measured as well. For the non-expanded bullets, the widths were measured at the centers of each petal and the pre-made lines on the nose were used as a guide for the point of measurement.

Results

Quantitative

The expansion of the fired hollow point bullets was analyzed separately by width and length. All width measurements for each substrate thickness were averaged to determine the means with standard deviations as shown in Table 2 and Figure 8. Firing through no ballistic gelatin (cotton only) was the negative control, while firing through a full block of ballistic gelatin was the positive control. The average width for the negative control was 7.01 mm ± 0.17 mm with a range of 6.66 mm to 7.19 mm. The average width for the positive control was 12.91 mm ± 0.57 mm with a range of 12.17 mm to 13.70 mm.

Width (mm)	Full	7.6 cm	5.1 cm	3.8 cm	2.5 cm	1.3 cm	None
B1	12.46	12.53	12.06	12.19	10.94	10.10	6.92
	12.61	13.40	12.05	11.73	11.61	10.17	7.05
	12.59	13.27	12.16	12.47	10.21	9.59	7.12
B2	13.49	11.96	12.03	12.17	12.09	10.33	7.12
	13.66	11.71	11.97	12.16	11.69	10.53	7.07
	13.57	11.73	12.07	12.2	12.37	10.50	6.70
B3	12.17	12.90	12.17	11.92	12.44	11.71	7.15
	12.37	12.88	12.06	11.77	12.88	12.09	7.04
	12.69	13.11	12.09	11.65	11.88	10.87	7.15
B4	13.56	12.25	12.83	12.01	12.05	11.15	7.19
	13.70	12.36	12.44	12.14	11.97	12.14	7.00
	13.45	12.21	12.80	12.42	12.01	10.41	7.18
B5	12.43	12.32	12.16	11.74	11.86	13.00	6.91
	12.41	12.15	11.70	11.69	11.95	12.43	6.88
	12.49	12.36	12.04	12.09	11.92	9.16	6.66
Average	12.91	12.48	12.18	12.02	11.86	10.95	7.01
Std Dev	0.57	0.53	0.30	0.26	0.62	1.11	0.17

Table 2. Measurements of the width, in mm, of the three paired petals for each bullet fired through the experimental substrate thicknesses and the controls.

The average widths of the expanded bullets were 10.95 mm ± 1.11 mm, 11.86 mm ± 0.62 mm, 12.02 mm ± 0.26 mm, 12.18 mm ± 0.30 mm, and 12.48 mm ± 0.53 mm as the experimental substrate thickness increased. The ranges for the width of each thickness were also determined: 1.3 cm thick – 9.16 mm to 13.00 mm, 2.5 cm thick – 10.21 mm to 12.88 mm, 3.8 cm thick – 11.65 mm to 12.47 mm, 5.1 cm thick – 11.70 mm to 12.83 mm, 7.6 cm thick – 11.71 mm to 13.40 mm.

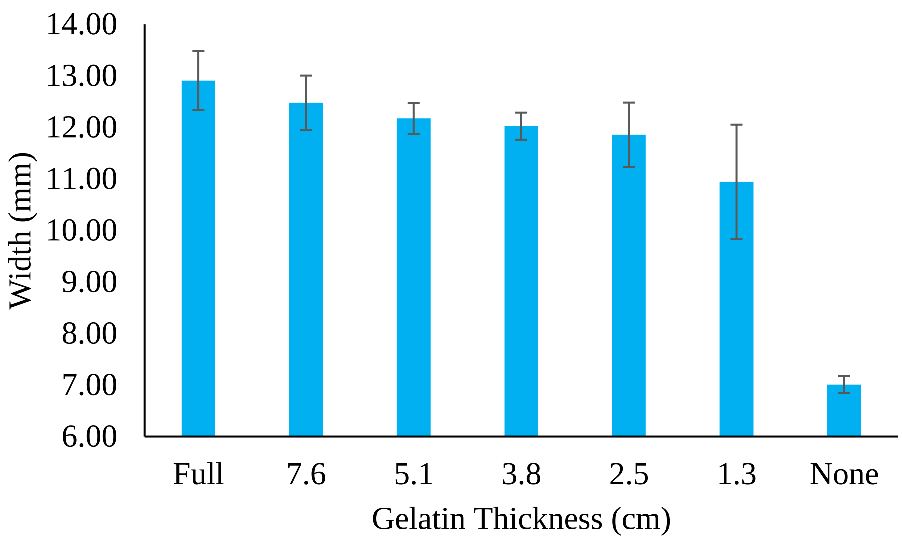

Figure 8. Bar graph of the average widths, in mm, for each gelatin thickness, in cm, with uncertainties.

The lengths for each fired hollow point were measured to determine the means with standard deviations as shown in Table 3 and Figure 9. The negative control had an average length of 17.48 mm ± 0.05 mm with a range of 17.41 mm to 17.55 mm. The positive control had an average length of 14.13 mm ± 0.17 mm with a range of 13.96 mm to 14.37 mm.

Length (mm)	Full	7.6 cm	5.1 cm	3.8 cm	2.5 cm	1.3 cm	None
B1	14.19	15.36	14.44	14.14	18.09	17.61	17.51
B2	13.96	14.83	14.43	14.45	14.92	15.45	17.45
B3	14.16	13.94	14.19	14.90	15.59	15.46	17.41
B4	13.96	14.46	14.15	14.38	15.65	17.65	17.50
B5	14.37	14.34	14.70	14.61	15.13	17.99	17.55
Average	14.13	14.59	14.38	14.50	15.88	16.83	17.48
Std Dev	0.17	0.54	0.22	0.28	1.28	1.27	0.05

Table 3. Measurements of the length, in mm, for each bullet fired through the experimental substrate thicknesses and the controls.

The average lengths of the expanded bullets were 16.83 mm ± 1.27 mm, 15.88 mm ± 1.28 mm, 14.50 mm ± 0.28 mm, 14.38 mm ± 0.22 mm, and 14.59 mm ± 0.54 mm as the experimental substrate thickness increased. The ranges for the length of each thickness were determined: 1.3 cm thick – 15.45 mm to 17.99 mm, 2.5 cm thick – 14.92 mm to 18.09 mm, 3.8 cm thick – 14.14 mm to 14.90 mm, 5.1 cm thick – 14.15 mm to 14.70 mm, 7.6 cm thick – 13.94 mm to 15.36 mm.

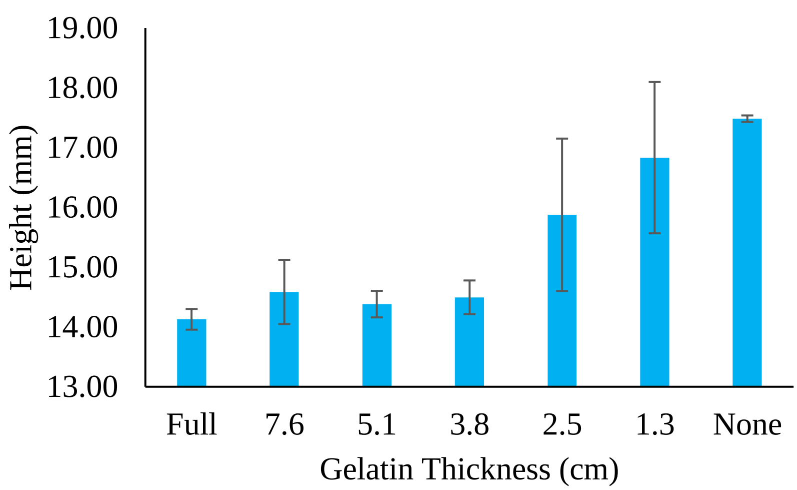

Figure 9. Bar graph of the average heights, in mm, for each gelatin thickness, in cm, with uncertainties.

The impact velocities from each gelatin thickness were collected in feet per second as shown in Table 4.

Impact Velocity (fps)	Full	7.6 cm	5.1 cm	3.8 cm	2.5 cm	1.3 cm	None
B1	973	1021	1023	949	936	1008	993
B2	1010	1047	1026	956	962	999	1002
B3	975	969	1024	989	989	1058	1011
B4	1021	1007	1092	994	1028	1031	996
B5	971	1043	1062	1022	1000	1026	1004
Average	990	1017.4	1045.4	982	983	1024.4	1001.2
Std Dev	23.64	31.6	30.75	29.82	35.36	22.85	7.05

Table 4. Impact velocities, in feet per second, of each bullet fired through the experimental substrate thicknesses and the controls.

The average impact velocities of the fired bullets were 1001.2 fps ± 7.05 fps, 1024.4 fps ± 22.85 fps, 983 fps ± 35.36 fps, 982 fps ± 29.82 fps, 1045.4 fps ± 30.75 fps, 1017.4 fps ± 31.6 fps, and 990 fps ± 23.64 fps from no gelatin to full gelatin. The range of impact velocities for all rounds was 936 fps – 1092 fps.

Qualitative

Amongst the fired hollow point samples for the experimental substrate thicknesses, there were noticeable visual differences between and within bullets because they did not all expand the same way. In some bullets, four or five of the petals would be curled back while the remaining would be upright or angled out in partial expansion. There were also some occurrences where the petals would expand at an angle towards a neighboring petal. The controls had the most consistent expansion – or lack thereof – compared to the experimental samples. They appeared to all look similar without much obvious visual variation between the petals.

Discussion

The goal of this research was to determine if there were changes in hollow point bullet expansion as there were changes in tissue thickness. Using ballistic gelatin as a human tissue simulant and an overlaying chamois as a human skin simulant, hollow point ammunition was fired into varying thicknesses of the gelatin and the recovered bullets were measured for comparison. This information supplements the understanding of wound ballistics of hollow points, which is slowly becoming a more researched topic as the ammunition becomes more prevalent at shooting scenes. There are multiple external factors that can influence their expansive properties, including manufacturing and impact velocity. Tissue thickness can also be added as a contributor to hollow point bullet expansion because of the results found through these experiments.

The average width measurements of the bullets show the trend of a decrease in width as there is a decrease in gelatin thickness. In practice, it would be difficult to distinguish exact thicknesses, but small ranges could be determined instead. This allows for any uncertainty to be accounted for and can make it easier to conclude where the bullet passed. The average length measurements show the trend of an increase in length as there is a decrease in gelatin thickness for the thinner slices. The heights of the expanded bullets for the 3.8 cm, 5.1 cm, and 7.6 cm thicknesses are similar to one another, which is indicative that the bullet's height does not vary as much as its width. Since there are trends in the bullets' measurements, there is a minimum thickness for maximum expansion. Once at this point, any thicker gelatin will not result in significant changes in width and height. This minimum thickness can be found following more extensive research into this relationship between gelatin thickness and hollow point expansion. Accounting for uncertainty, some of the thicknesses overlap, but there are opportunities to see a decrease in uncertainty with a future study including a greater quantity of cartridges per thickness. Quantitatively analyzing the expansion of hollow points through varying thicknesses is important, but qualitative analysis should not be overlooked. Observing the bullet expansion and seeing the differences between petals of the same bullet can be further studied to understand the variability of expansion. This research can also be built upon by creating a larger-scale study that includes greater samples and thicknesses to create a calibration curve of change in expansion width and length as there is a change in substrate thickness at a pre-determined impact velocity. This experiment was limited to Fiocchi hollow point ammunition, so examining other manufacturers of 9mm Luger hollow points may lead to different results.

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