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TECHNICAL NOTE

ANTHROPOLOGY

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Bullet Caliber and Type Categorization from Gunshot Wounds in *Sus Scrofa* (Linnaeus) Long Bone

ABSTRACT: Studies on ballistic trauma to the ribs and thorax, cranium, and long bones demonstrate the potential of obtaining a bullet caliber from an entrance wound. In order to validate prior research on caliber estimation in bone tissue and assess the viability of bullet type determination based on the macroscopic evidence at the entrance wound, thirty fleshed pork (*Sus scrofa*) shoulders (humeri) were shot with either lead or copper jacketed bullets in one of three calibers; 0.22, 9 mm, or 0.38. Overall, our findings are consistent with previous research indicating that calibers can be grouped into "small" and "large" categories. Bullet type, lead or copper jacket, can be ascertained based on cortical flaking and the analysis of materials deposited around the entry wound. The addition of this evidence holds value in cases where no firearm or ballistic evidence is recovered from a crime scene.

KEYWORDS: forensic science, forensic anthropology, ballistics, gunshot wound, bullet caliber, bullet type

Evidence of ballistic trauma to the ribs and thorax (1,2), cranium (3–5), and long bones (6,7) can yield important investigative information. Research using the flat bones of the cranium found that the minimum diameter of the entrance wound can lead to a general caliber size estimation (3–5). "Small" calibers, such as 0.22, 0.25, 0.28, and 0.32, have been successfully distinguished from "large" caliber bullets, such as 0.38 or 9 mm (3–5). Berryman et al. (3) noted that the entrance wounds are within two measured calibers of the actual caliber used. While these broad categories do not allow for specific caliber estimation, investigators can eliminate various calibers of the suspected bullet.

High-velocity trauma inflicted on bone produces instantaneous failure of the bone without deforming the fragments. This permits reassembly for entry wound analysis (4,5,7). This study utilizes these observations to attempt to determine caliber as well as note any changes to the bone based on the type of bullet used.

The specific categorization of bullet type, be it lead or copper, has the potential to add another dimension to the evidence of ammunition used. DiMaio defines a bullet wipe as the ring of soot around the entry point of a bullet in clothing, contrary to the belief of it being lead from the bullet passing through the fabric (8). He states that only the first layer of clothing will have this "bullet wipe" or soot ring. As this study did not analyze any clothing or soft tissue, a bullet wipe in the context of this study is the potential deposit of lead or copper to the bone from the bullet upon impact. Entry wounds were examined to determine if any differences between wounds from lead versus copper jacketed bullets exist. Scanning electron microscopy–electron dispersion X-ray (SEM-EDX) was also utilized to analyze any potential trace bullet wipe left upon impact.

Some common issues observed in previous studies include the sheer number of calibers, and examining the effect intermediate targets may have on the flight path of a bullet as well as the range of bullet designs and how bone reacts to the different forces involved (2–7). The elastic modulus of a bone may be exceeded at different loads depending on the bone's architecture, hence affecting the overall fracture pattern. Bone density, anatomical region, and age of the bone must also be considered as important variables in wound dynamics (4,5,7,9).

The microstructure of bone plays a critical role in mitigating the formation of cracks due to impacts (10). The energy from an impact is diverted along the lamellar cement lines as well as through the fluids contained in the Haversian and Volkman's canals, canaliculi, and lacunae. The totality of the microstructure's individual energy absorption results in slowing the rate of crack formation and may arrest propagation altogether. A high-energy event such as a ballistic impact results in fast propagating cracks that overcome the mitigating effect of the lamellae (10). Other studies detail crack propagation on a macroscopic and histological level (11–13).

The diaphysis of a long bone is essentially a dense cortical bone cylinder with a medullary cavity. The dense cortical bone is required to provide stability and rigidity to the skeleton (14). The porous trabecular portion is made up of bony spicules arranged in trajectories along the major tensile and compressive lines. The role of trabecular bone is to dampen stresses applied to the articular surface (15).

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When hit by a high-velocity impact as seen in ballistic wounds, the load is applied so rapidly that the bone reacts as a stiff and brittle material (16). The energy is projected through the outer table of cortical bone and explodes into the medullary cavity. Due to this mechanism of energy propagation, a beveled entrance wound is found in long bones that have undergone ballistic trauma (2,17). This results in many small fragments that exhibit no deformation and can be reconstructed almost seamlessly (5,7,16). Directionality of a gunshot wound to a bone can be determined utilizing both the bone displacement seen in the fragments as well as external beveling noted on the entry surface, which reinforces the importance of reassembling the wound area (1,2).

The different components of terminal, or wound, ballistics when assessing bone damage are essential. Terminal ballistics has been greatly explored concerning soft tissue and is well understood. The velocity at which a bullet enters the body can have a large effect on the type and size of wound created. The faster a bullet is moving through tissue, the less time the tissue has to react to the impact. The velocity is directly related to the cavitation left in the wound tract. Temporary cavitation is the elastic reaction of the tissue to the projectile as surrounding soft tissue is forced outward by the bullet and almost immediately fills the space behind the bullet as it passes (18). Permanent cavitation is caused by the shearing and compressive forces of the projectile as it tracks and tears through the tissue in a way that it cannot fall back into the wound path (18). The faster the bullet moves through the soft tissue, the larger the permanent cavity. In flight, bullets tend to yaw. Yaw is the manner in which a bullet tumbles sideways during its flight. When a bullet has higher velocity, it is able to physically spin faster and the yaw is reduced (19). With less yaw, a bullet is more stable and therefore enters the tissue at a straighter trajectory. If a bullet has more yaw, the trajectory has a greater angle of entry into the soft tissue and, consequently, the cavity is larger (19).

The bullet caliber influences the velocity due to the differences in grain (mass). To illustrate this, the 9 mm ammunition used in this study is 124 grain, while the 0.38 ammunition is 158 grain. While the two calibers measure the same physical dimension of 9 mm, the 0.38 bullet is heavier and will have a lower speed but have a higher momentum upon impact. The 124 grain bullet will be quicker but have less impact momentum. The energy a bullet has upon impact is more closely related to its mass instead of diameter, as demonstrated by the equation for kinetic energy; $KE = WV^2/2g$ where g is gravitational acceleration, W is the mass in kilograms, and V is the velocity in meters per second (8). It must be noted that the firearms used in this study had differing muzzle velocities, which will have some influence on the kinetic energy upon impact.

The design of the bullet used will also affect how the soft tissue is damaged. Bullets that have a lead tip often disfigure because of the forces imparted onto the leading edge of the bullet as it enters and passes through the tissue (8). Expanding tip and other soft-pointed bullets with no jacket tend to leave a larger cavity due to this effect. Bullets with a full jacket have greater density, do not disfigure, and leave a smaller cavity (8). The effect of the bullet design is of primary interest in this study, specifically if there is a difference in the wound margins when using a plain lead bullet versus a copper jacketed bullet. We predict a difference in the bone damage as the method of force absorption differs between a lead bullet and a copper jacketed bullet. A lead bullet deforms on impact with surfaces that are less dense, such as bone tissue. They are known as yielding bullets and can absorb some of the energy of the impact and flatten. A full copper jacket resists yielding to the forces imparted onto the bone and the bullet largely retains its original shape (8).

Materials and Methods

Sample Description

Thirty specimens of *Sus scrofa* L. (domestic pig) humeri were used as an analog for human long bone. Each pork shoulder was intact, with skin and underlying muscle tissues attached to the bone. Each of these specimens was shot once with a handgun at close range (approximately 0.75 m) perpendicular to the length of the diaphysis using a specific caliber. After shooting, each specimen was stored in a freezer until the removal of soft tissue. The resulting bone fragments for each specimen were stored at room temperature (~19°C) in a storage cabinet in the laboratory. Reconstructed humeri were stored in the same manner.

Firearms and Ammunition

Three different calibers of bullets were used: 0.22, 9 mm, and 0.38. The 0.22 caliber firearm used lead round-nose Blazer® CCI 0.22 long rifle ammunition. The 9 mm ammunition was a full copper jacket Dominion® brand centerfire bullet. Finally, lead round-nose Dominion® brand centerfire 0.38 special ammunition was used. The firearms used were a High Standard™ Supermatic, a Forjas Taurus™ Semi-Automatic, and a Smith and Wesson® Model 639, respectively. It is important to note that 9 mm and 0.38 calibers are in fact the same size. A 0.22 caliber bullet measures 5.65 mm in diameter, while a 9 mm and a 0.38 caliber each measure 9.00 mm.

Shooting

The pork shoulder segments were placed on their side, parallel to the ground. There were ten specimens used for each caliber, and each shoulder was shot once with the intended target being in either the mid-shaft region or head of the humerus, depending on which specimen was being used. The range of each shot was approximately 0.75 m. The shooting of all specimens was completed at once. A few samples of each caliber of lead bullet were recovered for analysis; however, no copper jacketed bullets were recovered.

Sample Assessment

After shooting, the pork shoulders were frozen until cleaning. The shoulders were first thawed and boiled in water. The majority of soft tissue was removed by cutting it away from the bone using scissors to prevent any blades from contacting the bone. The remaining tissue was removed using Tergazyme®, and then steamed to remove the remaining cartilaginous tissues. Once cleaned, they were stored in a dry cabinet on a tray. Each bone was photographed using a Canon® 60D digital SLR camera. The bones were analyzed by recording the degree of comminution in affiliation with the entrance wound, considering Rogers' guidelines (20). The diameter of each entrance wound was measured to the nearest hundredth of a millimeter using a Sylvac® Model S 235 electronic caliper. There were no measurements taken regarding the exit wound, as it does not impart any diagnostic information regarding the size of the bullet (21). Damage to the mid-shaft or humeral head was sustained by six bones using the 0.22 firearm, eight bones by the 9 mm firearm, and six bones using the 0.38 special firearm.

Bullet Wipe Analysis

Examination of some of the bone fragments yielded evidence of a bullet wipe. This evidence is commonly described as a gray or black ring around the circumference of an entrance hole formed by a bullet (8,22). A sodium rhodizonate test has been recommended as a quick test for the presence of lead (23). As the wipe was observed on bone, it was decided to use SEM-EDX to obtain the chemical data to identify the elements present in the bone wipe. Bullet fragments associated with the wipe were also subjected to the same analysis. A JEOL 6400 SEM operated at an acceleration voltage of 20 kV and a probe current of ~1 nA were used. These data were collected for 15 sec for both the bullet and bone samples. All samples were coated with a thin layer of carbon to minimize charging effects. This analysis yields energy-dispersive data in a chromatograph and an associated scanning electron micrograph.

Statistical Analysis

The measurements obtained from the minimum diameter of the entry wounds were compared using a nonparametric Kruskal–Wallis test as well as a *post hoc* test via IBM SPSS Statistics (24) to determine if the median diameter of each caliber were significantly different from one another (Table 1).

Results and Discussion

Caliber Categorization

A bullet's caliber is reported in either imperial or metric measurements. Of the three calibers used in this study, only two different diameters of bullet were used. Using the 0.22 lead bullets, six humeri sustained enough damage to necessitate reconstruction prior to analysis. The median measurement of the entry wound in this sample set was 8.00 mm, with no statistical outliers. Of the ten humeri shot with a 9 mm copper jacketed bullet, eight humeri were analyzed as the remaining two did not sustain any damage. The median entrance wound size resulting from the 9 mm bullet was found to be 9.69 mm, again with no statistical outliers. Six humeri sustained enough damage to necessitate reconstruction for analysis. The median entrance wound size was 10.02 mm, without any data outliers. Figure 1 shows the distribution of the measurements for each caliber. Due to the small number of samples, nonparametric statistics were used. The null hypothesis, that there were no differences between the median entrance wound size for each caliber, was calculated using the Kruskal–Wallis test. Differences were found between a 0.22 caliber entrance wound and a 0.38 caliber entrance wound, as well as a 0.22 caliber entrance wound and a 9 mm entrance wound

TABLE 1—*Kruskal–Wallis and* post hoc *pairwise comparison results.*

Sample	Test statistic	p-Value	Decision
Overall	$H = 9.946$	0.007	Reject H_1
0.22–9 mm	$T = 2.687$	0.022	Reject H_1
0.22–0.38	$T = 2.831$	0.014	Reject H_1
9 mm–0.38	$T = 0.339$	0.734	Fail to reject H_2

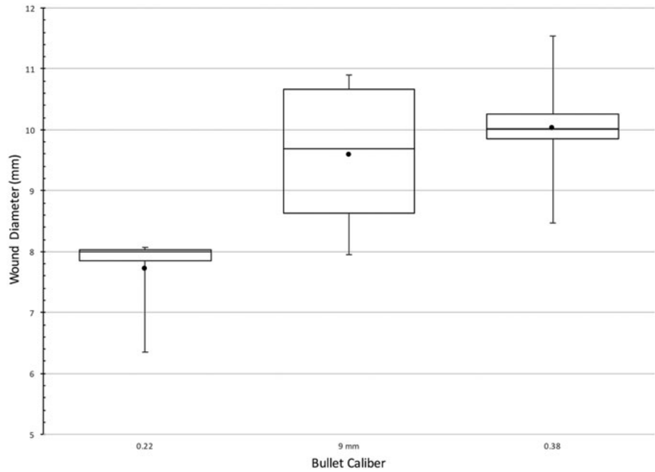

FIG. 1—*Box plot showing the distribution of measurements of wound diameter for each caliber.*

($p = 0.007$), rejecting the null hypothesis. Following the Kruskal–Wallis test, a pairwise comparison *post hoc* test was completed. There was no difference between a 0.38 caliber entrance wound and a 9 mm entrance wound ($p = 0.734$). It was determined that while the type of bullet may influence the force dissipation and the fracture mechanism, the diameter of the entrance wound is not affected when the bullet composition is changed. The results of the pairwise comparison show that a 0.22 caliber entrance wound is significantly different than a 9 mm/0.38 entrance wound. When comparing the damage from a 0.22 caliber bullet to that of a 9 mm bullet, each was found to produce statistically different entrance wound diameters ($p = 0.022$). The same is true between a 0.22 and a 0.38 caliber wound ($p = 0.014$). Berryman et al. (3), Ross (4) and Paschall and Ross (5) found that it was possible to estimate whether a "small" or "large" caliber bullet was used to inflict damage on cranial bones. A 0.22 caliber fell into the small bullet category, while the 0.38 and 9 mm bullets were deemed a large caliber. Our study has found parallel results using long bones.

Bullet Type Estimation

As previously noted, a 9 mm bullet and a 0.38 caliber bullet each measure 9 mm in diameter. For this reason, a 9 mm copper jacketed bullet and a 0.38 caliber lead bullet were used to observe possible differences between jacketed bullets verses unjacketed bullets. The differences were twofold: observing the transfer of material to the bone and the presence or absence of cortical bone flaking.

Locard's principle (25) states that any contact between two items will result in the transfer of material between the two surfaces, allowing one to anticipate the presence of lead or copper particles on the bone at the point of contact. In this study, a lead bullet resulted in lead being macroscopically visible on the margins of the reconstructed entrance wound even after the cleaning process (Fig. 2). The lead was observed on all twelve samples inflicted with the lead 0.22 or 0.38 bullets. Samples exhibiting bullet wipe were found to have bright areas under backscatter electron imaging in the SEM (Fig. 3). These correspond to areas with very high average atomic number and are explained by high lead (Pb) concentrations (Fig. 4). Antimony (Sb) was also sought due to trace Sb having been noted in two bullets examined from our sample. Due to an overlap between the CaKα and

FIG. 2—A Sus scrofa *(domestic pig) humerus exhibiting a circular defect due to a gunshot wound using a 0.38 caliber lead bullet. The double-ended arrow indicates the maximum measured diameter. The single arrow indicates the bullet wipe residue. (Photograph by S. Fairgrieve).*

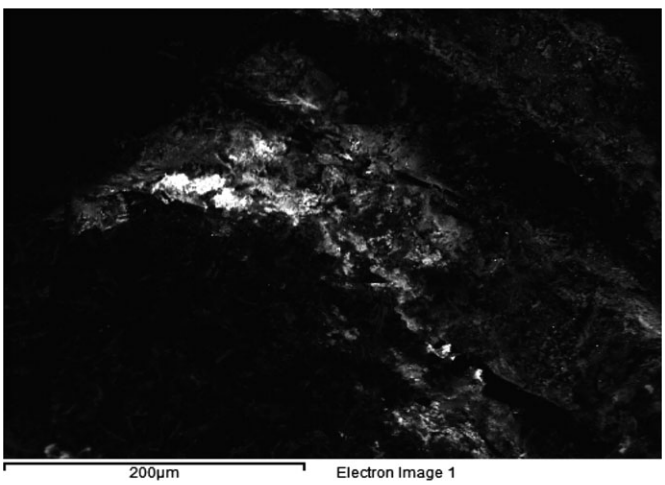

FIG. 3—*A scanning electron micrograph of bullet wipe characterized as being predominantly lead (Pb; bright area).*

SbKα X-ray lines and a high concentration of calcium (Ca) in bone, it was not possible to discern Sb from this analysis. The samples that were struck by a copper jacketed bullet did not macroscopically show the presence of copper particles. SEM analysis yielded no areas of brightness, nor were there any traces of Cu detected through energy-dispersive probe analysis. Therefore, it cannot be said that the copper was washed away in the

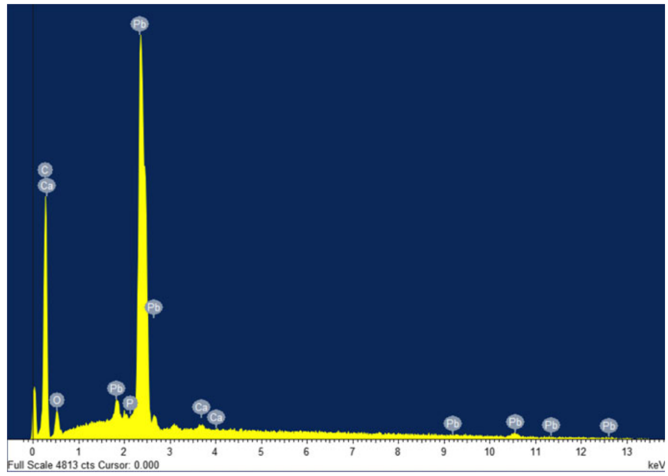

FIG. 4—*An energy-dispersive spectrum obtained on an approximately 10 μm^2 area on the bright feature depicted in Fig. 2. The Pb peak is clearly indicated as are the $CaPO_4$ (calcium phosphate) contained in the bone (Ca, P, O, peaks) with additional traced of Na, K, Mg.*

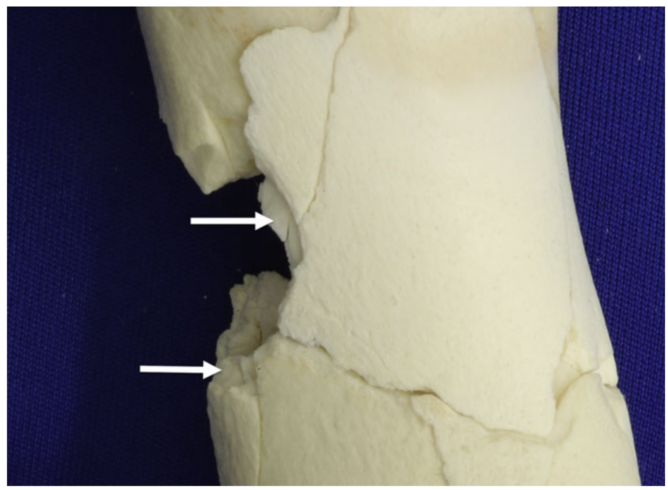

FIG. 5—*A detailed view of an entrance wound caused by a 9 mm copper jacketed bullet demonstrating cortical flaking (arrows) and fan-shaped crack propagation. Note the absence of bullet wipe. (Photograph by S. Fairgrieve).*

cleaning process, the particles are simply not visible to the naked eye or the copper is just not present. Based on this study, it can be said that the presence of lead on the margin of the entrance wound is indicative of the use of a lead bullet.

When using a lead bullet, the bones fracture through the entire table of the bone without any cortical flaking around the margins of the entrance wound (Fig. 2). When a copper jacketed bullet was used, flaking was observed at the margins of the entrance wounds (Fig. 5). Cortical flaking in bone can be likened to that of rock spalling. For example, Dierderichs and Martin (26) found that on the edge of excavation boundaries, compressive forces can lead to microcracks at the grain scale. These microcracks eventually lead to the failure of the rock. This failure is evidence of a high-energy release and results in spalls (26). By extrapolation, bone flakes (which may be referred to as spalls) are caused by a failure in tension within the bone tissue along the inner table. This failure is due to the compressive forces being applied during the penetration of the bone by the projectile. Similar to a rock spall, the portions of bone that are not flaked away show a fan of energy propagation, which extend away from the location of the initial impact (Fig. 5). This study proposes that this difference in fracture pattern, cortical flaking versus none, is due to the yielding nature of the type of bullet used. Lead bullets are softer than bone, and when they contact the bone they assume some of the impact energy and flatten (27). Copper jacketed bullets are denser than the bone tissue and are not deformed on impact (27). They are not able to assume energy from the impact, which leaves the energy to disperse within the bone. The energy propagates between the osteon layers, resulting in cortical flakes. Therefore, the presence of cortical flaking is associated with trauma on bone from a copper bullet, while the absence of flaking is indicative of a bullet made of lead. The characteristics of bullet wound morphology from full metal jacket bullets are supported by Rickman and Smith's research (28).

The largest limitations of this study are the limited ammunition sizes and types. This limited the caliber estimation portion of this study because only two groups of entry wound sizes were compared. Both the research previously done and this study confirm that calibers can be grouped into small versus large based on damage to bone (3–5). Future studies should include a more diverse assortment of calibers to determine whether specific caliber estimation is possible. Future research should also focus on the effects of other types of bullets, such as hollow point or soft-point jacketed bullets. It would be of value to see how a soft-point jacketed bullet affects long bone tissue and if cortical flaking occurs, as these bullets are composed of both yielding and nonyielding materials. An increase in the sample size would be beneficial, as normality may be obtained in the measurements of entrance wounds. Increasing the sample size would remedy sampling constraints.

Additionally, as this study only looked at gunshot wounds inflicted at a perpendicular angle and from a fixed distance, it would be beneficial for future studies to investigate angled impacts from various distances from longer and closer ranges.

Finally, while ballistic impact to *S. scrofa* bone is comparable to human bone, a validation study on any differences between the two is recommended to ensure porcine bone is a suitable analog.

This study has forensic relevance in cases where no bullet is recovered from the scene or the victim of a gunshot wound. The wound characteristics found on the bone may be used to indicate the type and caliber of bullet that caused the wound. A forensic anthropologist or pathologist would be able to look at the size of the entrance wound, the presence of lead on the margins of the wound, and the presence or absence of cortical flaking to approach the question of the size and type of bullet used to inflict that wound. We are in agreement with the conclusion that SEM analysis is underutilized in the analysis of ballistic trauma (28). This research lends itself to the now more focused description of ammunition used during the search and seizure of evidence. While this study does not identify the actual bullet that was used to shoot the victim, it does provide additional information that is germane to an investigation.

Conclusion

The findings of this study are consistent with the results generated regarding caliber categorization in cranial bones (3–5). It was found that a 0.22 caliber entrance wound is a significantly different size than those generated using a 9 mm bullet and a 0.38 caliber bullet, regardless of the type of bullet used. Because a 9 mm and a 0.38 are the same physical size, they produce entrance wounds that are of indistinguishable size.

This study found that cortical flaking on long bone gunshot wounds is indicative of the use of a jacketed bullet. We also found that lead wipes are macroscopically visible on bone that has been shot with lead bullets. If an investigator were to take sample swabs from a wound and conduct a metallurgic analysis, they can conclusively say which material the projectile was made of if it had not been recovered.

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