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TECHNICAL NOTE
ANTHROPOLOGY; CRIMINALISTICS

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Detection of Gunshot Primer Residue on Bone in an Experimental Setting—An Unexpected Finding*

ABSTRACT: Pork ribs with intact muscle tissue were used in an experimental attempt to identify bullet wipe on bone at distances from 1 to 6 feet with 0.45 caliber, full metal jacket ammunition. This resulted in the unexpected finding of primer-derived gunshot residue (GSR) deep within the wound tract. Of significance is the fact that the GSR was deposited on the bone, under the periosteum, after the bullet passed through a Ziploc® bag and *c.* 1 inch of muscle tissue. It is also important to note that the GSR persisted on the bone after the periosteum was forcibly removed. The presence of primer-derived GSR on bone provides the potential to differentiate gunshot trauma from blunt trauma when the bone presents an atypical gunshot wound. In this study, the presence of gunshot primer residue at a distance of 6 feet demonstrates the potential for establishing maximum gun-to-target distance for remote shootings.

KEYWORDS: forensic science, gunshot residue, SEM-EDX, forensic anthropology, gunshot trauma, ballistics, firearms examination

A recent skeletal forensic case presented a fractured rib with a missing segment suspected to be a gunshot wound, but the fracture lacked the typical bevel associated with a bullet. In an attempt to verify that a bullet produced the trauma, a scanning electron microscope (SEM) equipped with an energy dispersive X-Ray analyzer (EDX), was used to visually and compositionally examine the bone for lead or other metals commonly associated with bullet wipe (i.e., residual bullet trace). No bullet wipe was found, leading the authors to design a study to determine how metal from a bullet would appear on experimentally shot bone using SEM-EDX. Round nose lead and copper jacketed bullets were used with the expectation of seeing bullet wipe in the form of a metallic streak. Although bullet wipe could not be detected on the experimentally shot bone, particles in high concentration were observed over the bone surface, even at some distance away from the fracture site. Upon EDX analysis of these areas trace amounts of lead (Pb), barium (Ba), and antimony (Sb)—components of a bullet primer—were detected. The original purpose for this research was revised to demonstrate that primer-derived gunshot residue (GSR) can be detected on bone deep within a wound track. Pork ribs were selected as they were readily accessible and provided the simulation of a deep wound tract, as at least 1 inch of muscle tissue overlaid each bone.

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Scanning electron microscopy has long been used for obtaining images with resolution and depth of field superior to those of light microscopy. The primary sample requirement is to be stable under vacuum while the surface is being scanned with an electron beam. Interactions of the beam of electrons with the surface of the sample produce a number of signals, each of which are useful and have their own separate detector. Secondary and backscatter electron signals are primarily used for imaging, backscatter differing in that they are higher energy and can be useful in screening higher atomic mass areas from lower atomic mass areas. Characteristic x-rays are also produced by the electron bombardment. These can be measured simultaneously and allow identification of virtually every element on the periodic chart. Scanning electron microscopy in combination with energy dispersive x-ray spectrometry is a very powerful analytical instrument for materials analysis and is extremely useful in the forensic application at hand.

Discharge of a firearm begins when the primer is crushed by the firing pin driving hot gases and burning particles into the propellant (1,2). Ignition of the propellant occurs within a matter of a few ten thousands of a second and the high pressure from the heated gases propels the bullet out of the cartridge casing (1,2). Primer vapors are created through this reaction and condense into droplets forming gunshot primer residue (1,2). Primer condensation particles are comprised mainly of Pb, Ba, and Sb and can contain elements such as aluminum (Al), silicon (Si), sulfur (S), potassium (K), and calcium (Ca) that can originate from sources such as etched bullets, cartridge casings, or barrels (1,2).

According to Meng and Caddy (1) "When a gun has been fired, gunshot residues can arise from the primer, propellant, lubricants, and metals that are found in the bullet, bullet jacket, cartridge casing, and gun barrel." Within forensic literature the term "gunshot residue" has been used to describe virtually any material exiting a fired weapon. For the purpose of this technical note, the authors wish to make clear that the materials being discussed are only and

specifically from the primer composition of modern ammunition. They will be called "gunshot primer residue or particles."

GSR primer particles typically possess a characteristic spheroidal-shape and a diameter in the range of 0.1–10 μm (2). "In fact, this particle morphology, when combined with the elemental composition, makes GSR quite distinct from many environmental particulates, including occupational particles such as lead aerosols, automobile exhaust, and condensation fumes that may contain one or more elements of GSR" (2). Wolten et al. (3,4) proposed a classification scheme that divided GSR into two categories: unique and characteristic. The unique category included the following compositions: (a) Pb, Sb, and Ba, (b) Ba, Ca, and Si with a trace of S, (c) Ba, Ca, and Si with a trace of Pb, if copper (Cu) and zinc (Zn) are absent, and (d) Sb and Ba. Wolten et al. (3,4) based their system of GSR particle classification on their results from *c.* 80 hand samples from people whose occupation involved metals or compounds of Pb, Ba, and Sb. Particles defined in the unique category were not found among these hand samples (3,4). The compositions in the consistent category, (a) Pb and Sb, (b) Pb and Ba, (c) Pb, (d) Ba if S is absent or in trace amounts and (e) Sb, were defined as such as they were found in these occupational residues and therefore were not unique to GSR (3,4).

Wallace and McQuillan (5) in their examination of cartridge-operated industrial tools revised GSR classification further. Some particle compositions that were previously defined as unique by Wolten et al. (3,4) were found in Wallace and McQuillan's (5) examination of cartridge-operated industrial tools. Based on Wallace and McQuillan (5), Pb–Sb–Ba and Sb–Ba are the only particles that are designated as a unique GSR particle. It should be noted that Torre et al. (6) removes Sb–Ba particles from the unique category if the particle contains sulfur at a major level. Indicative or support particles are also defined in Wallace and McQuillan (5) and it is their system of classification, as well as analysis, that was followed during this study.

Brown et al. (7) developed an automated image analysis technique to measure the amount of GSR particles (all particles) within and around a gunshot wound. They used Andorran goat hides in this study that were comprised of the hair, epidermis, dermis, and some subcutaneous fat. Firings into the goat skin were carried out at distances of contact, 2.5, 5, 10, 20, 30, 45, and 60 cm, using a 0.22 caliber semiautomatic rifle and CCI brand long rifle solid point, high velocity ammunition. Although the results of repeated shots fired from the same distance were highly variable, there was a nonlinear decreasing relationship between firing range and amount of GSR deposited. This is one of the few studies (7–9) that investigates the presence of GSR within the wound tract and confirms its presence within subcutaneous tissue indicating that it travels with the bullet. Intuitively, one would think that GSR would be wiped from the bullet as it passed through the skin; however, the presence of GSR particles in subcutaneous tissue indicates that it continues into the wound tract and could deposit on underlying bone. In a follow-up study some of the same authors (8) found that GSR particles were heavily concentrated in the wound tract only for contact and close range shots (≤2.5 cm) with a more uniform particle distribution between the wound tract and the skin surfaces for shots fired from distances greater than 2.5 cm.

Methods

Six pork ribs were shot at distances of 1 through 6 feet at one-foot increments using 0.45 caliber, full metal jacket bullets. Ribs were placed at a fixed location. Distance was determined by measurements placed on a long wooden board (2 × 4), which was secured in a fixed position. The pistol was gripped against the distance board with the muzzle at the desired distance marker. In this manner distance was closely approximated for each rib.

Ribs, with the meat intact, were placed inside a plastic Ziploc® bag and shot with the bullet penetrating the plastic, *c.* 1 inch of muscle tissue, and the bone from external to internal surfaces. The Ziploc® bags were used to simulate skin, which our ribs were lacking. After each rib was shot, the meat was removed using scissors. The periosteum was forcibly stripped from the bone starting with the loose flap located *c.* 1–2 cm near the fracture site. This loose periosteal flap was observed in each of the experimentally shot ribs. The ribs were placed in paper bags and put into an incubator to dry at 40°C (*c.* 104°F) for 5 days. The ribs needed to be completely dry so that vacuum could be achieved in the SEM without moisture contaminating the instrument's vacuum system. After the ribs were dried they were removed and allowed to cool. The ribs were not coated with conducting material, such as gold or carbon. Even though the bone substrate is nonconductive, no problems with charging were observed. The fracture pattern associated with each rib was examined in order to verify the entrance side of the bone. For ease of placement of the rib into the specimen holder (similar Ted Pella part number 15384), the exit side of the rib was defined as the side of the bone directly opposite to the determined entrance side. The ribs were then positioned in the specimen holder so that the analysis could be performed on either the entrance or exit side of the bone and then placed in the specimen chamber of the SEM (Fig. 1). Analysis was conducted at the Middle Tennessee State University Interdisciplinary Microanalysis and Imaging Center, visually using the Hitachi VP-SEM S-3400N and elementally using the Oxford INCA Energy 200 Dispersive X-Ray Analyzer.

Preliminary research using the secondary electron setting of the SEM and elemental analysis yielded trace amounts of Pb–Ba–Sb in areas of high concentration of what was originally thought to be GSR. The authors propose that the particles observed in the preliminary tests were fat droplets with embedded GSR. This would explain the trace levels of Pb, Sb, and Ba, the particle's tendency to melt under the electron beam, and failure to adequately repeat these elemental results. This led to the implementation of a more effective method of locating GSR primer particles on bone (i.e., to set the SEM to backscatter detection). EDX was performed on particles that were suspected to be GSR. The spectrum was obtained using 25 kV at a working distance of 10 mm and was manipulated

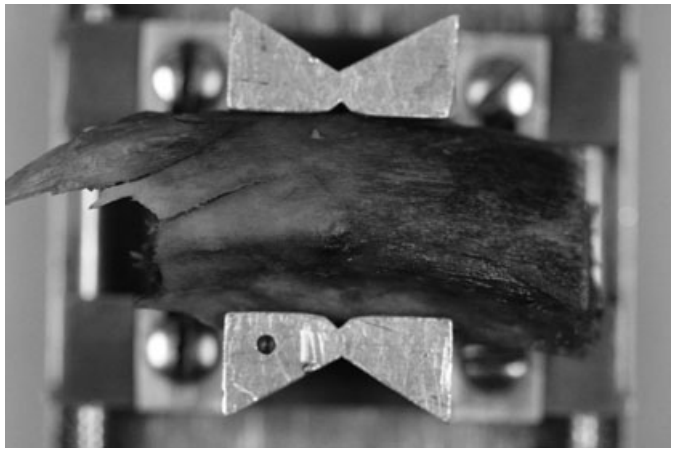

FIG. 1—*Segment of shot pork rib in a SEM specimen holder (similar Ted Pella part number 15384).*

as described by Wallace and McQuillian (5) to demonstrate major, minor and trace elemental levels.

Results and Discussion

Unique and indicative GSR primer particles were found on pork rib specimens shot at distances ranging from 1 foot to 6 feet. A study by Faller-Marquardt et al. (9) may be used to formulate a hypothesis as to how these GSR primer particles come to be under the periosteum of a shot pork rib. They analyzed 68 contact shots to the neurocranium and found that in 95.6% the periosteum around the bony entrance hole exhibited circular detachment from the outer table, and radial tears of the elevated periosteum with flaps facing outward (9). Soot soiling and deposition of gunpowder particles were present on the exposed underside of the periosteum. Faller-Marquardt et al. (9) state that these changes are due "to the powder gases which expand under the scalp overlying a flat bony surface when a contact shot is fired." More notably, this study also included experimental distance shots at 2 m away from the skull of a calf and at 30–40 cm from flat bones covered with soft tissue. A small collar of periosteal detachment was observed without deposition of soot and demonstrates that the bullet alone may be able to produce periosteal detachment (9). Faller-Marquardt et al. (9) propose that as the bullet perforates the entrance region, the tissue is "radially accelerated and displaced centrifugally causing shearing forces between the consecutive layers." This explains the mechanism of separation of the periosteum from the underlying bone in distance shots, allowing the underlying bone to be exposed to GSR and the deposition of GSR primer particles.

In the present study a rib shot at a gun-to-target distance of 1 foot with a Winchester 0.45 caliber, 185 grain, full metal jacket bullet experienced minimal bullet contact or the bullet passed in such close proximity that the bone was fractured. The resulting fracture could easily be interpreted as blunt force trauma (Fig. 2*a,b*); however, upon microscopic examination and EDX analysis, unique and indicative GSR primer particles were identified on the subperiosteal bone surface. Even at a distance of *c.* 2 cm from the fracture site GSR primer particles are found. One particle in particular (Fig. 3) is a unique GSR primer particle with the EDX confirming the presence of Pb, Ba, and Sb (Fig. 4). The authors hypothesize that when the bone fractures, the periosteum is elevated from the bone surface, exposing it to GSR. It is further hypothesized that the base of a bullet acts as a vacuum to trap vapor, distributing it throughout the wound tract and eventually depositing GSR primer particles on exposed bone. Finding gunshot primer residue particles on the bottom of discharged bullets (10) adds weight to this hypothesis. Despite the forceful removal of soft tissue necessary to prepare the bones for this study, the GSR primer particle deposits remained intact. If gunshot primer residue can be shown to persist beyond decomposition, then it may prove to be a valuable tool in differentiating fractures associated with atypical gunshot wounds from those produced by blunt force trauma.

Microscopic examination of a rib shot at a gun-to-target distance of 6 feet with an American Eagle 0.45 caliber, 230 grain, full metal jacket bullet also revealed unique and indicative GSR primer particles. The particle depicted in Fig. 5 is confirmed by EDX as a unique GSR primer particle whose composition exhibits Pb, Ba, and Sb (Fig. 6). The spectral results indicate major levels of Pb and Ba with levels bordering on the major/minor level for Sb as defined by Wallace and McQuillan (5) (Fig. 6). These were not the only particles found in this study, but they serve to illustrate the unique GSR particles that were encountered. In addition, countless indicative particles as defined by Wallace and McQuillan (5) were found on the bone surface.

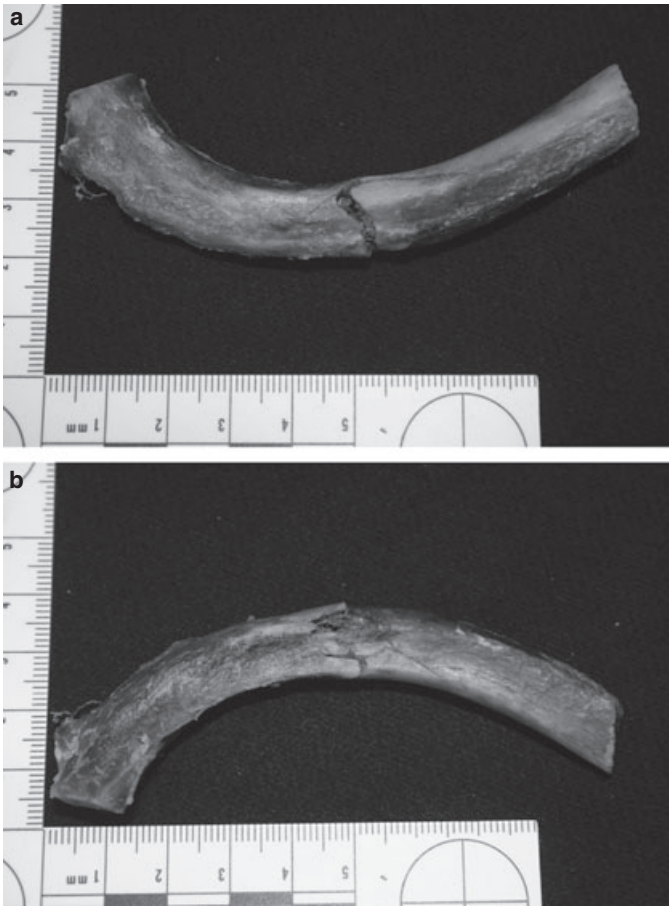

FIG. 2—*Fractured pork rib shot at a gun-to-target distance of 1 foot with a Winchester 0.45 caliber, 185 grain, full metal jacket bullet. (a) Inferior view. (b) Superior view.*

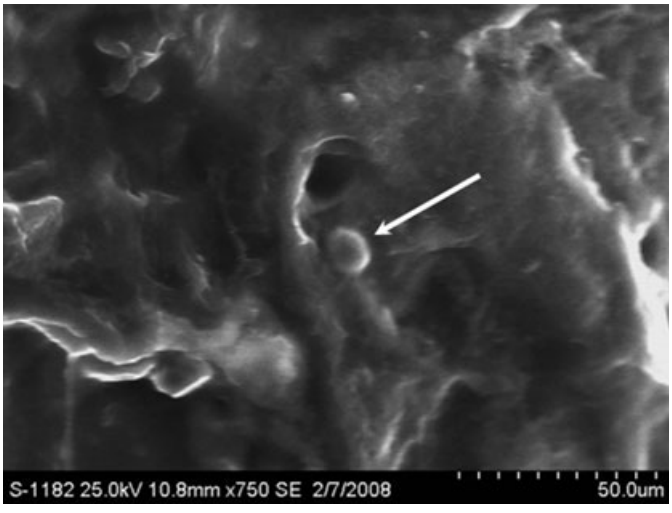

FIG. 3—*Unique GSR particle (indicated by the arrow) on a pork rib shot at a gun-to-target distance of 1 foot with a Winchester 0.45 caliber, 185 grain, full metal jacket bullet.*

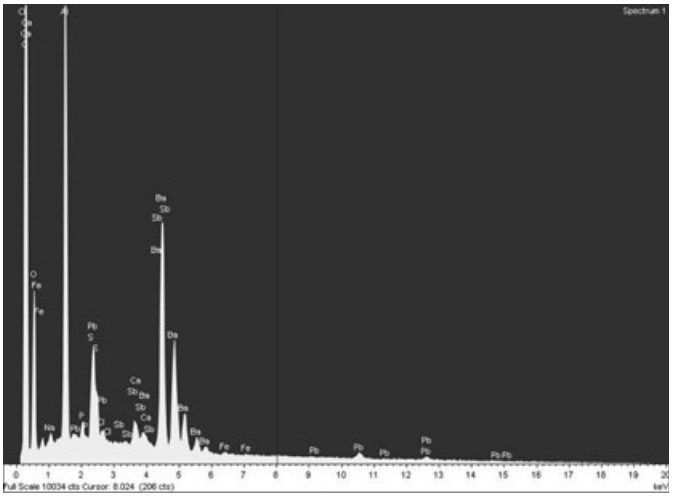

FIG. 4—*EDXA spectrum result of the GSR particle on a pork rib shot at a gun-to-target distance of 1 foot with a Winchester 0.45 caliber, 185 grain, full metal jacket bullet.*

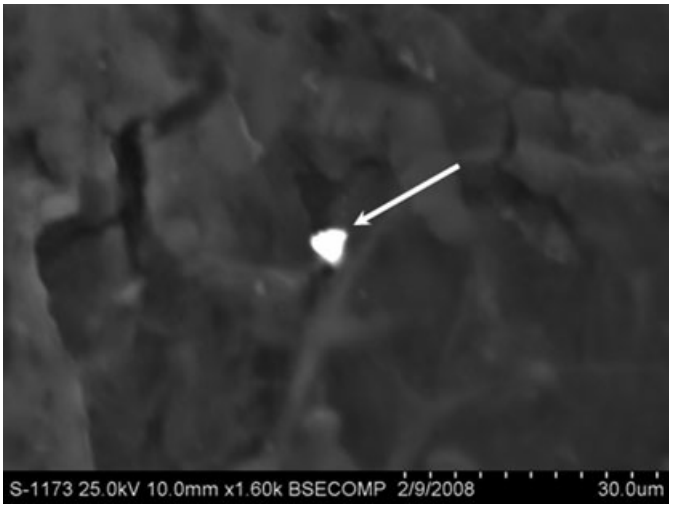

FIG. 5—*Unique GSR particle (indicated by the arrow) on a pork rib shot at a gun-to-target distance of 6 feet with an American Eagle 0.45 caliber, 230 grain, full metal jacket bullet.*

This study has demonstrated that primer-derived GSR occurs well below the level of subcutaneous tissue and is present on bone, even after the forceful removal of the periosteum. GSR primer particles can be found deep within the wound track when the gun-to-target distance is 6 feet; however, this study did not test beyond this distance and the range at which GSR primer particles can no longer be detected is not known. Further research in this area, especially in regard to specific lot, caliber, and manufacturer of ammunition, may enable a more precise determination of gun-to-victim distance. In addition, if GSR primer particles are found to be present after decomposition then these observations can be used to verify a gunshot wound to bone in the absence of a typical gunshot wound fracture pattern.

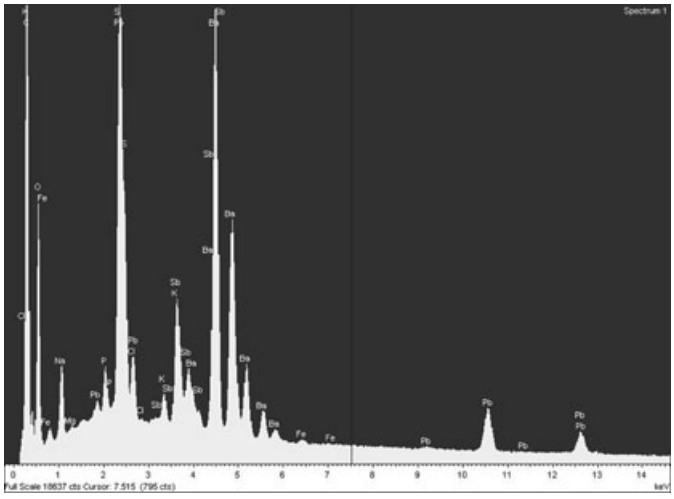

FIG. 6—*EDXA spectrum result of the GSR particle on a pork rib shot at a gun-to-target distance of 6 feet with an American Eagle 0.45 caliber, 230 grain, full metal jacket bullet.*

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