Radiodense Bullet Wipe Around Osseous Entrance Gunshot Wounds*

Ashley L. Lukefahr,[1,4] M.D.; Jennifer M. Vollner[2,3] Ph.D.; Bruce E. Anderson,[2,3] Ph.D.; and David C. Winston,[2,4] M.D., Ph.D.

[1]Banner University Medical Center – Tucson, Tucson, A.Z

[2]Pima County Office of the Medical Examiner, Tucson, AZ.

[3]The University of Arizona School of Anthropology, Tucson, AZ.

[4]The University of Arizona Department of Pathology, Tucson, AZ.

Corresponding author: Ashley L. Lukefahr, MD. E-mail: lukefahr@email.arizona.edu

*Presented at the 72nd Annual Meeting of the American Academy of Forensic Sciences, February 17-22, 2020, in Anaheim, CA.

ABSTRACT: "Bullet wipe" is the material deposited by a bullet on any surface with which it comes into contact after it is fired and may contain debris from the gun barrel, including particles of primer and metal fragments from previously fired bullets. X-ray analysis is a non-destructive method by which traces of metallic elements can be visually detected. The analysis of osseous defects for radiodense bullet wipe (RBW) assists in determining the presence or absence of perforating gunshot wounds, especially in fragmented, skeletonized remains.

The aim of our current study was to determine the frequency of RBW around entrance firearms injuries that perforated bone. We prospectively analyzed entrance gunshot wounds for RBW over a three-year period using digital X-ray analysis (n=59). We retrospectively reviewed the corresponding autopsy reports to determine the frequency of RBW by biologic sex, reported ancestry, age-at-death, location of wound, manner of death, range of fire, bullet caliber, and presence of bullet jacket. Data were analyzed by Fisher's exact test or Chi-square test with significance levels accepted at $p<0.05$.

RBW was present in 66% (n=39) of examined cases. Decedent characteristics did not significantly alter RBW distribution, including biologic sex (p=0.75), reported ancestry (p=0.49), and age-at-death (p=0.43). Additionally, the location of the osseous entrance gunshot wound, manner of death, range of fire, and cartridge caliber did not affect RBW detection. All cases involving non-jacketed rounds (n=5) showed RBW (p=0.30).

To our knowledge, this study is the first to report the frequency of RBW detection from osseous entrance gunshot wounds.

KEYWORDS: radiodense bullet wipe, osseous gunshot wound, entrance gunshot wound, postmortem radiology, forensic pathology, forensic anthropology, autopsy

Postmortem interpretation of gunshot wound trauma relies on an accurate and thorough analysis of the characteristics of the wound. In the absence of distinguishing soft tissue injuries or supplemental information from a scene investigation, other methods of analysis, including various biochemical or spectroscopy techniques, must be relied upon to determine residue from a firearm. These ancillary techniques are particularly useful when decomposition changes, postmortem animal activity, or other factors preclude a successful visual examination of tissues for gunshot wound trauma. One such technique is X-ray analysis of bone, which is a non-destructive method by which residue from small arms cartridges can be readily detected (1).

Small arms cartridges comprise a cartridge case, a primer, propellant, and a bullet or projectile (2). Primers manufactured in the United States are made with compounds that include lead styphnate, barium nitrate, and antimony sulfide (2). Modern bullets are either non-jacketed lead or metal-jacketed (2). Lead bullets consist of lead mixed with tin or antimony and may be thinly coated with copper or copper alloy (2). Metal-jacketed bullets have a lead or steel core covered by a full or partial outside jacket of gilding metal (copper and zinc), gilding metal-clad steel, cupro-nickel (copper and nickel), or aluminum (2). Because of these properties, primer residue typically contains a combination of lead, antimony, and/or barium, while bullet residue from non-jacketed bullets is predominantly lead (3).

"Bullet wipe" is the term applied to the material deposited by a bullet on any surface with which it comes into contact after it is fired (4). Bullet wipe may contain microscopic fragments of the bullet, as well as debris from the barrel of the fired gun, including particles of primer and metal fragments from previously fired bullets (4). While it is known that X-ray analysis can be used to detect RBW, data regarding the frequency of RBW detection, and the factors which may affect the successful detection of RBW in osseous entrance gunshot wounds, are unreported.

Materials and Methods

A total of 59 cases of entrance gunshot wounds were radiographed post-autopsy over three years (May 2016 to March 2019) by one of two staff forensic anthropologists (co-authors on this paper). Digital X-ray analysis of osseous entrance gunshot wounds was performed using a portable, handheld X-ray system (KaVo NOMAD Pro, Brea, CA) (5) with 60 kV and 2.5 mA. In brief, the osseous element of interest was sandwiched between the X-ray source and a digital imaging sensor. The image from the X-ray exposure was automatically uploaded from the sensor to a computer software program (DEXIS, Brea, CA), with digital images available for capture. The primary rate limiting step was the ability to maneuver the hand-held digital sensor for radiography and the best results came when the X-ray source was perpendicular to the osseous element of interest. RBW was determined to be present if any amount of metallic fragments were detected by X-ray analysis (FIG. 1). None of the osseous wounds were subjected to a chemical cleaning prior to radiography.

Retrospective review of autopsy reports, medicolegal death investigator notes, and scene and autopsy photographs was performed utilizing MDILog V4 software (ORA, Inc., Big Rapids, MI), in order to identify the biologic sex, reported ancestry, and age-at-death of the decedent; manner of death; estimated range of fire; location of wound; cartridge caliber; and presence of cartridge jacket. As necessary, law enforcement investigators were contacted in order to supply information not readily apparent in the reviewed materials.

All interpretation of wound characteristics (estimated range of fire, location of wound) and manner of death certification was performed by one of six board certified forensic pathologists who performed the autopsy (one of whom is a co-author on this paper). Images of the gunshot wounds were not re-analyzed to confirm the conclusions stated in the autopsy report. In brief, range of fire was categorized as contact range if soot was visible on the skin or within the wound track or a muzzle imprint was visible; intermediate range if stippling was present on the skin surrounding the wound; and indeterminate range if no soot or stippling was demonstrated on the skin of the wound or within the wound track (2). In a case involving fragmentary and burned remains, the range of fire was determined based upon the known circumstances of the death and evidence from the scene investigation.

All information concerning the characteristics of the ammunition (caliber, presence of jacket) was determined by review of autopsy reports, medicolegal death investigator notes, scene photographs, and information provided by law enforcement investigators. In many cases, a photograph of a jacket fragment recovered at the time of autopsy served as the only indication that the involved projectile was jacketed; therefore, no determination was made as to whether the projectile was partially or fully jacketed. No analysis of any recovered projectiles, by a firearms expert or otherwise, was performed.

Data were analyzed by Fisher's exact test or Chi-Square test, with significance levels accepted at $p<0.05$ (GraphPad Prism 8.1.2, San Diego, CA).

Results

A total of 59 osseous entrance gunshot wounds were examined by digital X-ray analysis (FIG. 2). RBW was present in 66% of cases (n=39) and absent in 34% of cases (n=20). Analyzed cases included decomposed/mummified remains (n=1) and fragmentary/burned remains (n=1) and both had RBW detected (FIG. 3).

Biologic sex did not impact the successful detection of RBW, as 67% of men (n=31) and 62% of women (n=8) showed RBW. These values showed no statistically significant difference, with only random associations between biologic sex and RBW detection found by Fisher's exact test (p=0.75).

Reported ancestry did not significantly impact successful RBW detection, as 61% of Caucasians (n=20), 75% of Hispanics (n=12), 71% of African Americans (n=5), and 67% of Native Americans (n=2) showed RBW. Of the cases in which RBW was absent, 65% were Caucasian (n=13), 20% were Hispanic (n=4), 10% were African American (n=2), and 5% were Native American (n=1). These values showed no statistically significant difference, with only random associations between reported ancestry and RBW detection found by Chi-square test (p=0.49).

Age-at-death did not significantly impact RBW detection, as RBW was detected in 62% of those aged 11-20 years (n=5), 68% of those aged 21-30 years (n=15), 54% of those aged 31-40 years (n=6), 75% of those aged 41-50 years (n=3), 50% of those aged 51-60 years (n=3), 80% of those aged 61-70 years (n=4), 100% of those aged 71-80 years (n=2), and 100% of those aged 81-90 years (n=1). Of the cases in which RBW was not detected, 15% were individuals between the ages of 11 and 20 years (n=3), 35% were individuals between the ages of 21 and 30 years (n=7), 25% were between the ages of 31 and 40 years (n=5), 5% were between the ages of 41 and 50 years (n=1), 15% were between the ages of 51 and 60 years (n=3), and 5% were between the ages of 61 and 70 years (n=1). These values showed no statistically significant difference, with only random associations between age-at-death and RBW detection found by Chi-square test (p=0.43).

The location of the osseous entrance gunshot wound did not significantly impact RBW detection, as RBW was found in 62% of wounds in the frontal bone (n=5), 70% of wounds in the right parietal bone (n=16), 44% of wounds in the left parietal bone (n=4), 100% of wounds in the right temporal bone (n=4), 67% of wounds in the occipital bone (n=4), 100% of wounds in the hard palate (n=3), 100% of wounds in the mandibular condyles (n=1), and 67% of wounds in the sternum (n=2) (FIG. 4). Of the cases in which RBW was absent, 15% were from the frontal bone (n=3), 35% were from the right parietal bone (n=7), 25% were from the left parietal bone (n=5), 5% were from the left temporal bone (n=1), 10% were from the occipital bone (n=2), 5% were from the sternum (n=1), and 5% were from a rib (n=1). These data did not meet the conditions necessary for valid statistical evaluation by Fisher's exact test or Chi-square test.

Manner of death did not impact RBW detection, as RBW was found in 67% of homicides (n=18) and 72% of suicides (n=21). When RBW was not detected, the manner of death was classified as homicide in 45% of cases (n=9), suicide in 40% of cases (n=8), accident in 10% of cases (n=2), and undetermined in 5% of cases (n=1). These data did not meet the conditions necessary for valid statistical evaluation by Fisher's exact test or Chi-square test.

Range of fire did not impact RBW detection, as RBW was detected in 65% of contact range wounds (n=22), 69% of intermediate range wounds (n=9), and 67% of indeterminate range wounds (n=8) (FIG. 5). When RBW was not detected, the range of fire was determined to be contact range in 60% of cases (n=12), intermediate range in 20% of cases (n=4), and indeterminate range in 20% of cases (n=4). These data did not meet the conditions necessary for valid statistical evaluation by Fisher's exact test or Chi-square test.

Of the fifty-five cases involving handguns, six cases were excluded from the analysis of the effects of cartridge caliber on RBW detection, due to insufficient information. RBW was detected in 100% of cases involving .22 caliber cartridges (n=3), 50% of cases involving .25 caliber cartridges (n=1), 56% of cases involving 9 mm caliber cartridges (n=9), 50% of cases involving .357 caliber cartridges (n=1), 64% of cases involving .380 caliber cartridges (n=7), 75% of cases involving .40 caliber cartridges (n=9), and 33% of cases involving .45 caliber cartridges (n=1) (FIG. 6). Of the cases in which RBW was not detected, 6% involved .25 caliber cartridges (n=1), 39% involved 9 mm caliber cartridges (n=7), 6% involved .357 caliber cartridges (n=1), 22% involved .380 caliber cartridges (n=4), 17% involved .40 caliber cartridges (n=3), and 11% involved .40 caliber cartridges (n=2). These data did not meet the conditions necessary for valid statistical evaluation by Fisher's exact test or Chi-square test.

Of the fifty-five cases involving handguns, eight cases were excluded from the analysis of the effect of jacket on RBW detection, due to insufficient information. Information regarding whether the jackets were partial or full was not available. RBW was detected in 67% of cases involving jacketed rounds (n=28) and 100% of cases involving non-jacketed rounds (n=5) (FIG. 7). These values showed no statistically significant difference, with only random associations between presence of jacketed rounds and RBW detection found by Fisher's exact test (p=0.30).

Two cases involved shotguns and two cases involved rifles. RBW was detected in a contact range shotgun wound (12-gauge birdshot) of the sternum and an intermediate range shotgun wound (12-gauge slug) of the frontal bone. RBW was detected in a contact range rifle wound (.22) of the right temporal bone. RBW was not detected in a contact range rifle wound (.223) of the left parietal bone.

Discussion

To our knowledge, this paper is the first to report the overall prevalence of RBW in osseous entrance gunshot wounds and to describe the characteristics of the decedent (biologic sex, reported ancestry, age-at-death, manner of death), wound (estimated range of fire, location of wound), and ammunition (caliber, presence of jacket) as they pertain to the successful detection of RBW. Because the ability to detect bullet wipe is invaluable for differentiating blunt force trauma from firearm injuries and identifying gunshot wounds in the setting of decomposition, the data presented here offer information that is essential for the postmortem evaluation of osseous gunshot wounds.

Given that osteological differences (including morphology, composition, and/or response to biomechanical forces) exist in relation to an individual's biologic sex, reported ancestry, and age (6), these factors are important to consider and analyze in the context of osseous entrance gunshot wounds. In addition, the location of the osseous defect is an important variable to analyze, given that thin bones, such as the squamous temporal, generally lack features, such as beveling, consistent with gunshot wound trauma (2). Furthermore, given that experimental data has shown increased range of fire correlates with the ability to detect gunshot residue (7), and manner of death correlates with both range of fire and location of gunshot wounds (8), these factors are also important to analyze. The data presented here support the contention that biologic sex, reported ancestry, age-at-death, location of gunshot entrance wound, manner of death, and range of fire, do not affect the frequency of RBW detection.

The most obvious utility for the information presented in this paper pertains to the analysis of skeletonized and fragmented remains. Even with the presence of beveling, a bony defect in a fragment of bone cannot definitively be identified as an osseous entrance gunshot wound from visual inspection alone, as many factors (including postmortem animal predation, blunt force trauma, and sharp force trauma) could result in a similarly appearing defect. As blunt force and sharp force implements have been shown to impart radiodense material onto soft tissues (9,10), the presence of radiodense material in and of itself is not specific evidence of a gunshot wound. The presence of radiodense material in osseous fragments in combination with scene findings or the known circumstances of the death may support the contention that an osseous entrance gunshot wound is most likely present. The data presented in this manuscript are derived from well-characterized entrance gunshot wounds, as the entrance gunshot wounds analyzed in this data set were from predominantly non-decomposed decedents where soft tissue and bone characteristics, the presence of a projectile, or the known circumstances of the death allowed for determination of wound characteristics (including range of fire). This information, therefore, helps to address the question of how frequently RBW can be detected under known real-world conditions and serves as a proof of concept of how this technique can be used under non-ideal conditions, especially when factors such as decomposition result in soft tissue loss. Concurrently, if X-ray analysis is performed on a fragment of bone suspicious for an osseous entrance gunshot wound and is negative for radiodense material, the presence of an entrance gunshot wound cannot be excluded, given that even under well-characterized circumstances RBW is detected only 66% of the time.

Postmortem imaging analysis, including X-ray and computed tomography (CT), has been used to not only identify retained bullets in penetrating gunshot wounds but as an adjunctive technique to gross inspection for the determination of entrance versus exit gunshot wounds and for determining the wound pathway (11). Comparative studies in bone have demonstrated the superiority of digital radiography versus CT and magnetic resonance imaging in detecting metallic gunshot residue particles from both fresh and cremated bone (12). These radiodense deposits also persist through intermediate targets, as shown by an experimental model utilizing porcine skin wherein X-ray analysis detected radiodense fragments on soft tissues from partial jacket rifle rounds at distances of 6 meters through an intermediate wooden target of 5 cm thickness (13).

Other ancillary techniques that may be used to address the presence of bullet wipe from gunshot wounds include biochemical tests, methods involving atomic absorption spectroscopy (AAS), neutron activation analysis (NAA), inductively coupled plasma-atomic emission spectroscopy (ICP-AES), proton-induced X-ray emission (PIXE), and scanning electron microscopy coupled with an energy dispersive X-ray analyzer (SEM-EDX). Biochemical tests can detect nitrite compounds, lead, barium, and antimony (14,15). Several methods involving AAS identify elements such as lead based on their light absorption at specific wavelengths (7,14). NAA can detect elements such as antimony, by characterizing the radioactive emissions following excitation by neutrons, but cannot detect lead (14,16). ICP-AES can detect trace amounts of lead, barium, and antimony by identification of light emission at specific wavelengths after excitation (17). PIXE is a non-destructive method that uses proton-induced X-ray emission spectra to identify trace elements such as lead (1,18). SEM-EDX is a non-destructive method that uses a focused electron beam to excite characteristic X-rays and identifies chemical elements such as lead, barium, and antimony in micrometer-sized gunshot residue particles (14, 19). Experimental data on animal and human tissues utilizing SEM-EDX (2,19) have shown that bullet wipe may be recovered from decomposed and macerated bone (20), bone submerged in seawater (21), cremated bone (22), and soft tissue that has undergone histopathologic processing (23). Given the persistence of bullet wipe in such varied circumstances and under such harsh environmental conditions, the value of bullet wipe detection as an ancillary analytical technique in the forensic setting should not be understated. The methodology employed in the current study lacks the ability to identify individual elements and is therefore not specific evidence of a gunshot wound defect. However, the availability and practicality of the instrumentation utilized in the current study, versus the availability of instrumentation such as SEM-EDX that may only be found in the specialized laboratory setting, makes it an appealing ancillary method for the forensic pathologist.

The data presented here also support the contention that cartridge caliber and the presence of a cartridge jacket do not affect the frequency of RBW detection. A limitation of this report is the inability to differentiate between partial and full jacket projectiles, due to the limits of the available information in our data set. This information is especially important to consider, given that conflicting information exists in the reported literature in regards to the presence of radiodense material in gunshot wound defects from partial versus full jacket projectiles. For example, experimental data on porcine models has shown that partial metal jacket 9 mm projectiles demonstrate multiple projectile fragments along osseous wound tracks, as analyzed by CT imaging, while full metal jacket 9 mm projectiles demonstrate no such radiodense material (24). In contrast, other experimental data on porcine models indicates that both partial and full metal jacket projectiles deposit radiodense material in fatty tissue in contact range handgun wounds, albeit less material compared to unjacketed lead projectiles, as analyzed by microCT (25). And experimental data utilizing human tissue and microCT has successfully detected radiodense fragments from entrance gunshot wounds from full jacket projectiles where the firing handgun was positioned up to 30 cm away from the target, even after decomposition (26) and charring from fire (27). Other investigative studies utilizing SEM-EDX have demonstrated radiodense material deposited onto animal bone by full metal jacket projectiles (28). The current study reflects a realistic and practical approach, as information about whether the projectile in question is partial or full jacket is not always readily available. Future research is necessary to analyze how the presence of a partial or full jacket affects the successful X-ray detection of RBW from osseous entrance gunshot wounds.

Although the current study is limited in scope, the data presented here confirm that digital x-ray analysis is a sensitive and practical technique for the successful detection of RBW from osseous entrance gunshot wounds. Further research is necessary to determine how factors such as postmortem interval, the presence of intermediate targets (including clothing), and more detailed ammunition characteristics (including full versus partial jacket) may alter the successful detection of RBW from osseous gunshot wounds.

References

1. Fischbeck HJ, Ryan SR, Snow CC. Detection of bullet residue in bone using proton-induced X-ray emission (PIXE) analysis. J Forensic Sci 1986;31(1):79-85.

2. DiMaio JVM. Gunshot wounds: practical aspects of firearms, ballistics, and forensic techniques. 3rd ed. Boca Raton, FL: CRC Press, 2016;1-28, 57-108.

3. Lantz PE, Jerome WG, Jaworski JA. Radiopaque deposits surrounding a contact small-caliber gunshot wound. Am J Forensic Med Pathol 1994;15(1):10-3. doi: 10.1097/00000433-199403000-00003.

4. Kieser DC, Carr DJ, Girvan L, Leclair SCJ, Horsfall I, Theis JC, et al. Identifying the source of bullet wipe: a randomized blind trial. Int J Legal Med 2013;127:951-5. doi: 10.1007/s00414-013-0874-z.

5. Gray JE, Bailey ED, Ludlow JB. Dental staff doses with handheld dental intraoral X-ray units. Health Phys 2012;102(2):137-42. doi: 10.1097/HP.0b013e318230778a.

6. Christensen AM, Passalacqua NV, Bartelink EJ. Forensic anthropology: current methods and practice. 2nd ed. London, U.K.: Academic Press an imprint of Elsevier, 2019;243-442.

7. Gagliano-Candela R, Colucci AP, Napoli S. Determination of firing distance. Lead analysis on the target by atomic absorption spectroscopy (AAS). J Forensic Sci 2008;53(2):321-4. doi: 10.1111/j.1556-4029.2008.00668.x.

8. Molina DK, DiMaio V, Cave R. Gunshot wounds: a review of firearm type, range, and location as pertaining to manner of death. Am J Forensic Med Pathol 2013;34(4):366-71. doi: 10.1097/PAF.0000000000000065.

9. Bajanowski T, Hüttenbrink K-B, Brinkmann B. Detection of foreign particles in traumatized skin. Int J Legal Med 1991;104(3):161-6. doi: 10.1007/BF01369722.

10. Fracasso T, Karger B. Two unusual stab injuries to the neck: homicide or self-infliction? Int J Legal Med 2006;120(6):369-71. doi: 10.1007/s00414-005-0052-z.

11. Giorgetti A, Giraudo C, Viero A, Bisceglia M, Lupi A, Fais P, et al. Radiological investigation of gunshot wounds: a systematic review of published evidence. Int J Legal Med 2019;133(4):1149-58. doi: 10.1007/s00414-019-02071-8.

12. Amadasi A, Borgonovo S, Brandone A, Di Giancamillo M, Cattaneo C. A comparison between digital radiography, computed tomography, and magnetic resonance in the detection of gunshot residues in burnt tissues and bone. J Forensic Sci 2014;59(3):712-7. doi: 10.1111/1556-4029.12304.

13. Schyma C, Placidi P, Schild HH. Radiological findings in gunshot wounds caused by hunting ammunition. An experimental study. Int J Legal Med 1996;108(4):201-5. doi: 10.1007/BF01369792.

14. Heard BJ. Handbook of firearms and ballistics examining and interpreting forensic evidence. 2nd ed. Hoboken, NJ: Wiley-Blackwell, 2008;241-69.

15. Andreola S, Gentile G, Battistini A, Cattaneo C, Zoja R. Forensic applications of sodium rhodizonate and hydrochloric acid: a new histological technique for detection of gunshot residues. J Forensic Sci 2011;56(3):771-4. doi: 10.1111/j.1556-4029.2010.01689.x.

16. Gibelli D, Brandone A, Andreola S, Porta D, Giudici E, Grandi MA, et al. Macroscopic, microscopic, and chemical assessment of gunshot lesions on decomposed pig skin. J Forensic Sci 2010;55(4):1092-7. doi: 10.1111/j.1556-4029.2010.01378.x.

17. Turillazzi E, Di Peri GP, Nieddu A, Bello S, Monaci F, Neri M, et al. Analytical and quantitative concentration of gunshot residues (Pb, Sb, Ba) to estimate entrance hole and shooting-distance using confocal laser microscopy and inductively coupled plasma atomic emission spectrometer analysis: an experimental study. Forensic Sci Int 2013;231(1-3):142-9. doi: 10.1016/j.forsciint.2013.04.006.

18. Warren MW, Falsetti AB, Kravchenko II, Dunnam FE, Van Rinsvelt HA, Maples WR. Elemental analysis of bone: proton-induced X-ray emission testing in forensic cases. Forensic Sci Int 2002;125(1):37-41. doi: 10.1016/s0379-0738(01)00614-4.

19. Berryman HE, Kutyla AK, Russell Davis J 2nd. Detection of gunshot primer residue on bone in an experimental setting-an unexpected finding. J Forensic Sci 2010;55(2):588-91. doi: 10.1111/j.1556-4029.2009.01264.x.

20. Taborelli A, Gibelli D, Rizzi A, Andreola S, Brandone A, Cattaneo C. Gunshot residues on dry bone after decomposition – a pilot study. J Forensic Sci 2012;57(5):1281-4. doi: 10.1111/j.1556-4029.2012.02119.x.

21. Lindström AC, Hoogewerff J, Athens J, Obertova Z, Duncan W, Waddell N, Kieser J. Gunshot residue preservation in seawater. Forensic Sci Int 2015;253:103-11. doi: 10.1016/j.forsciint.2015.05.021.

22. Amadasi A, Brandone A, Rizzi A, Mazzarelli D, Cattaneo C. The survival of metallic residues from gunshot wounds in cremated bone: a SEM-EDX study. Int J Legal Med 2012;126(4):525-31. doi: 10.1007/s00414-011-0661-7.

23. Wilber CG, Lantz RK, Sulik PL. Gunshot residue, ten years later. Am J Forensic Med Pathol 1991;12(3):204-6. doi: 10.1097/00000433-199109000-00006.

24. von See C, Stuehmer A, Gellrich N-C, Blum KS, Bormann K-H, Rücker M. Wound ballistics of injuries caused by handguns with different types of projectiles. Mil Med 2009;174(7):757-61. doi: 10.7205/milmed-d-01-4908.

25. Stein KM, Bahner ML, Merkel J, Ain S, Mattern R. Detection of gunshot residues in routine CTs. Int J Legal Med 2000;114(1-2):15–8. doi: 10.1007/s004149900124.

26. Cecchetto G, Amagliani A, Giraudo C, Fais P, Cavarzeran F, Montisci M, et al. MicroCT detection of gunshot residue in fresh and decomposed firearm wounds. Int J Legal Med 2012;126(3):377-83. doi: 10.1007/s00414-011-0648-4.

27. Fais P, Giraudo C, Boscolo-Berto R, Amagliani A, Miotto D, Feltrin G, et al. Micro-CT features of intermediate gunshot wounds severely damaged by fire. Int J Legal Med 2013;127(2):419-25. doi: 10.1007/s00414-012-0775-6.

28. Rickman JM, Smith MJ. Scanning electron microscope analysis of gunshot defects to bone: an underutilized source of information on ballistic trauma. J Forensic Sci 2014; 59(6): 1473-86. doi: 10.1111/1556-4029.12522.

Figure Legends

FIG. 1—*(A) Representative radiograph of an osseous entrance gunshot wound with RBW detected and (B) a representative radiograph of an osseous entrance gunshot wound with no RBW detected.*

FIG. 2—*(A) Representative radiograph of radiodense bullet wipe from an osseous entrance gunshot wound with (B) corresponding photograph of cutaneous entrance gunshot wound with punctate abrasions and (C) corresponding photograph of the external table of the osseous defect of the right parietal bone. The external table of the osseous defect (2C) is photographed prior to removal of the calvarium or brain with the edges of the defect showing a keyhole-like beveling pattern (partial internal and partial external beveling).*

FIG. 3—*(A) Radiograph of radiodense bullet wipe from an osseous entrance gunshot wound with arrow indicating radiodense material. Corresponding photograph (B) of the curvilinear defect from skeletonized, burned, and fragmented right temporal bone with arrow indicating relatively the same area as in 2A. After the radiograph was shot, the bones were rearticulated for the photograph. Note: A fragment of a copper jacket was recovered in adjacent residual soft tissues.*

FIG. 4—*The effects of location of entrance gunshot wound on the detection of radiodense bullet wipe.*

FIG. 5—*The effects of range of fire on the detection of radiodense bullet wipe.*

FIG. 6—*The effects of cartridge caliber on the detection of radiodense bullet wipe.*

FIG. 7—*The effects of cartridge jacket on the detection of radiodense bullet wipe.*

Figure 1

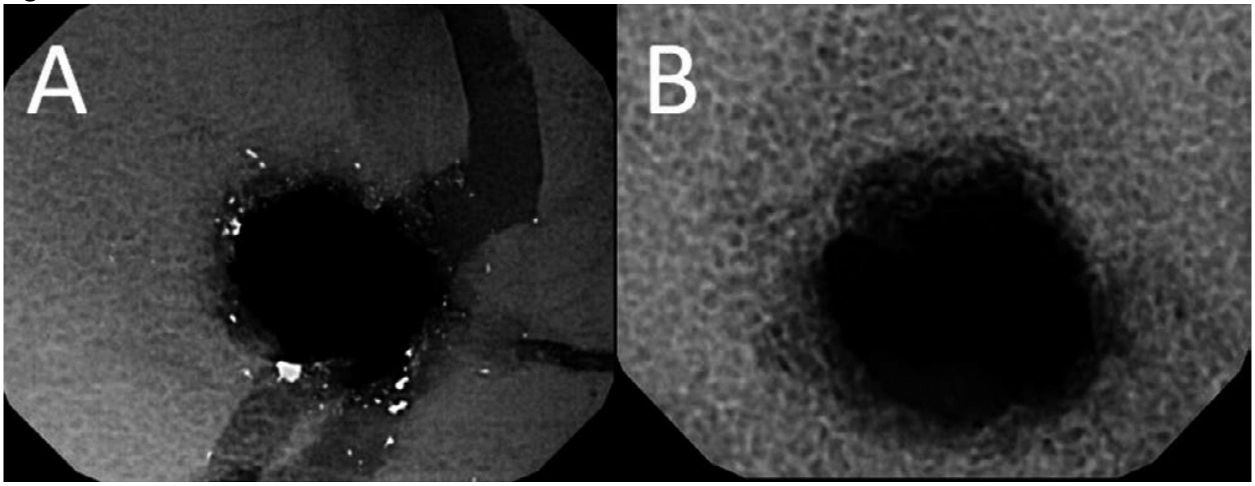


Figure 2

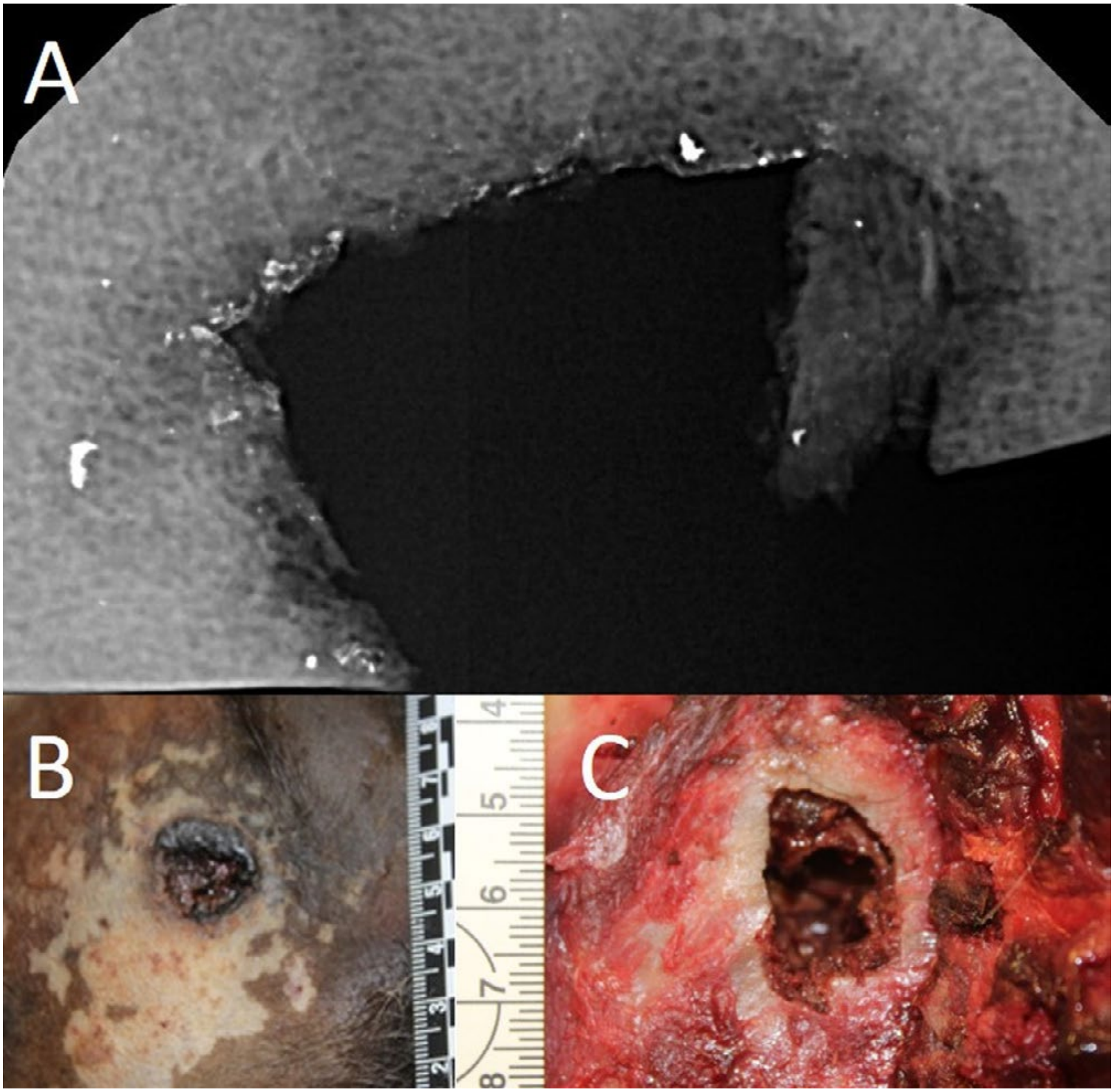


Figure 3

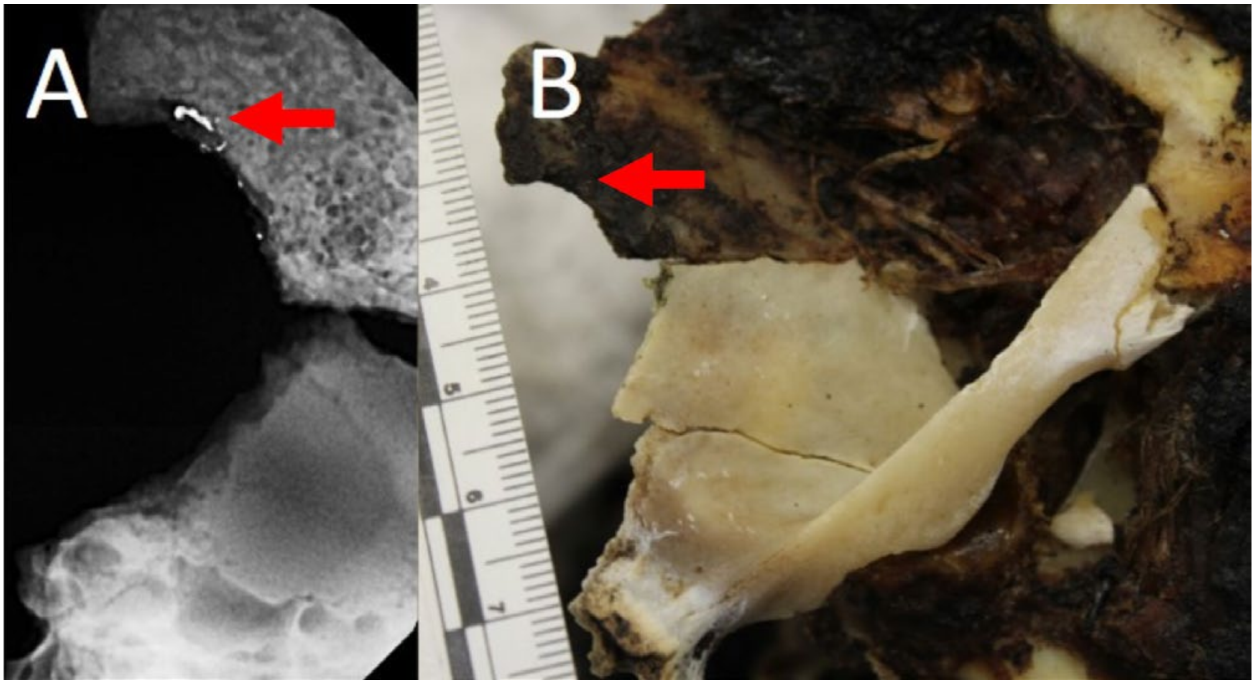


Figure 4

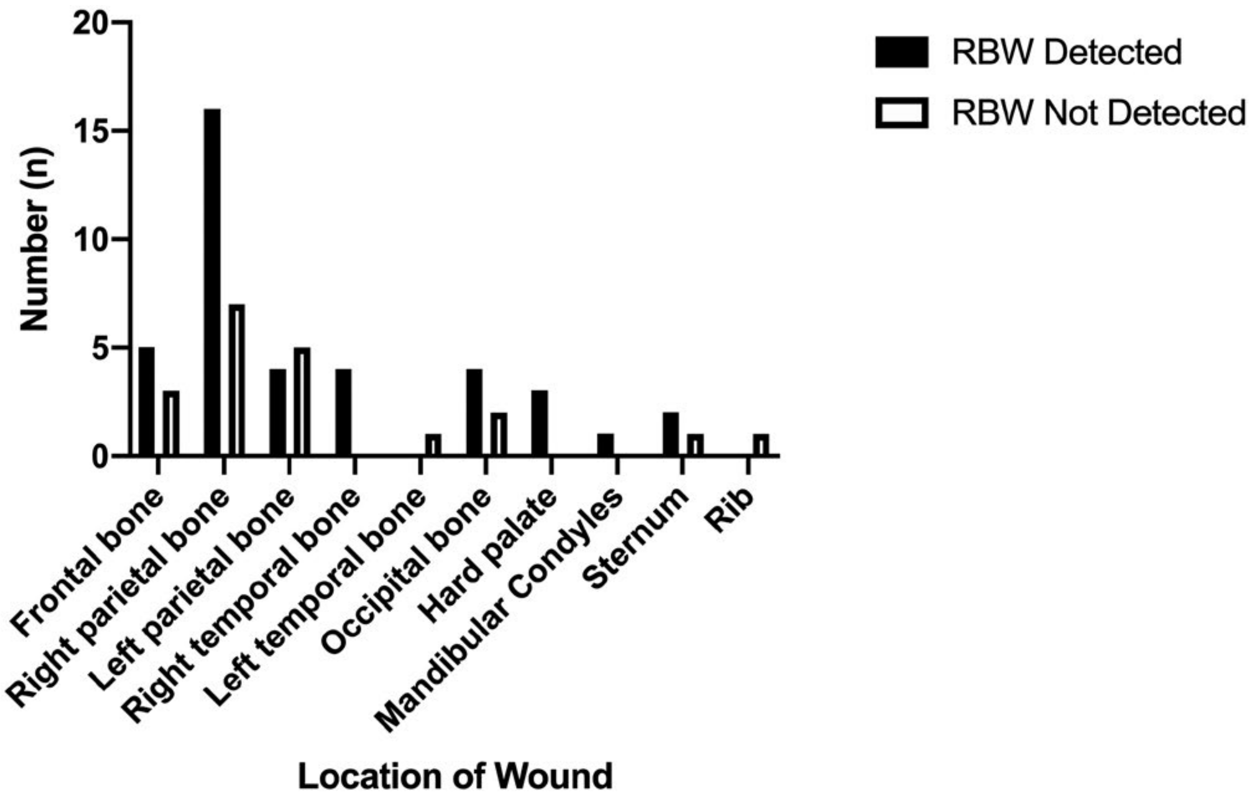

RBW Detected
RBW Not Detected
Number (n)
20
15
10
5
0
Frontal bone
Right parietal bone
Left parietal bone
Right temporal bone
Left temporal bone
Occipital bone
Hard palate
Mandibular Condyles
Sternum
Rib
Location of Wound

Figure 5

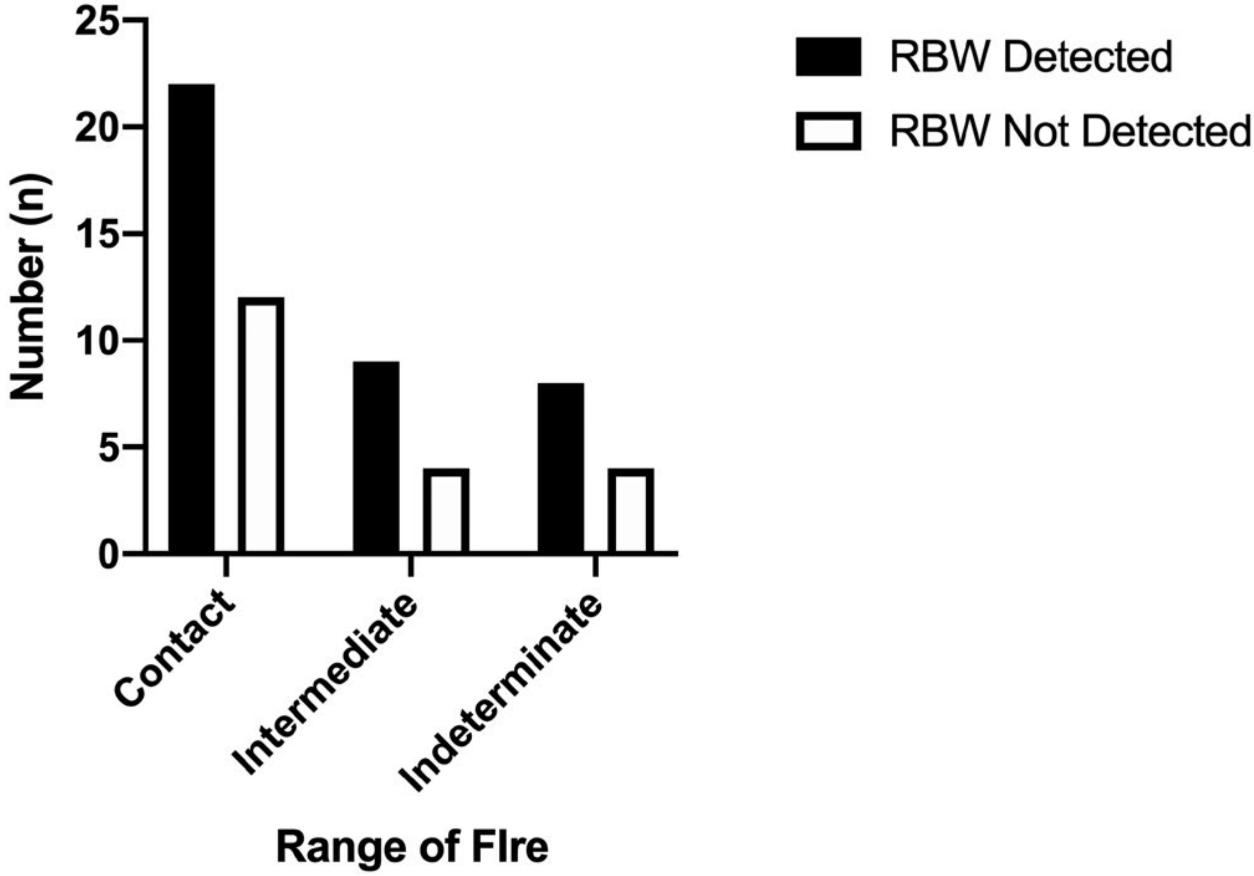
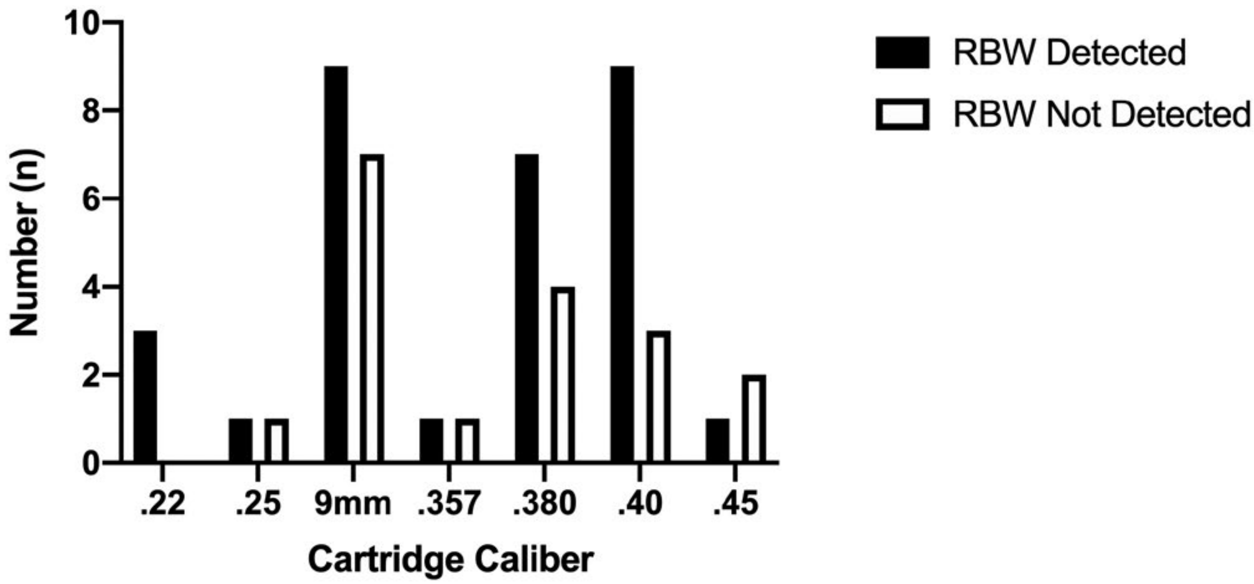
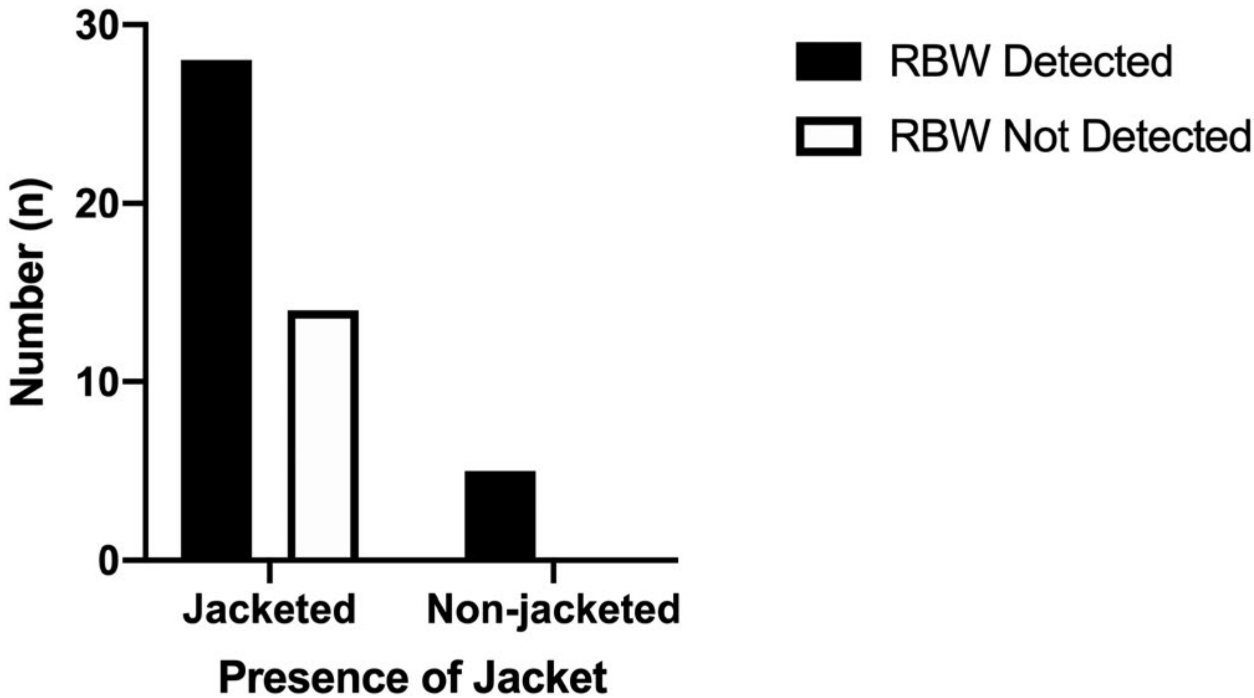

25
20
15
10
5
0
Number (n)
RBW Detected
RBW Not Detected
Contact
Intermediate
Indeterminate
Range of FIre

Figure 6



RBW Detected
RBW Not Detected
Number (n)
10
8
6
4
2
0
.22
.25
9mm
.357
.380
.40
.45
Cartridge Caliber

Figure 7


30
20
10
0
Number (n)
Jacketed
Non-jacketed
Presence of Jacket
RBW Detected
RBW Not Detected