Int J Legal Med (2012) 126:363–369
DOI 10.1007/s00414-011-0633-y

ORIGINAL ARTICLE

The survival of metallic residues from gunshot wounds in cremated bone: a radiological study

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Received: 30 March 2011 / Accepted: 5 October 2011 / Published online: 27 October 2011

Abstract In literature, many studies have been performed in order to investigate the presence of GSR ("gunshot residue") and metallic residues in general with radiological techniques on several types of material, but the survival of metallic residues on charred samples has never been systematically performed. In this study, 31 adult bovine ribs underwent a shooting test. Every rib was shot with a single bullet, at a near-contact shooting distance, using two kinds of projectile: 17 samples were shot with a full metal-jacketed bullet and the remaining 14 with an unjacketed bullet. After the shooting test, every rib underwent a "charring cycle" in an electric oven up to 800°C. Every sample underwent radiological investigation with conventional radiography, before and after the burning process, to evaluate any changes in number and distribution of metallic residues. Radiographs showed survival of radiopaque residues in every sample, even after the charring process, especially when the bullet used was of the unjacketed type.

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Keywords Forensic science · Forensic pathology · Forensic anthropology · Gunshot wounds · Cremation · Radiology

Introduction

The analysis of charred remains represents a tough challenge for the forensic pathologist and anthropologist. In fact, burning processes can cause severe morphostructural changes (like splits, shrinkage, crumbling), and recognizing the original morphology of a bone lesion can be very difficult [1–9]. In this scenario, the only aid may come from the presence of metal residues. In cases of gunshot injuries, radiographs can be used for the retrieval of the bullet or potentially important metallic parts of it from the propulsive charge as well as from the primer, the bullet, the cartridge case, and the firearm itself [10]. These residues can be observed in conventional radiographs as radiopaque, roughly round findings, located along the path traveled by the bullet through the tissues [11–19]. Gunshot residues can be found in any type of tissue the bullet traveled through, including the bone [20–22], and recent studies have shown the presence of GSR even under the periosteum [23].

Thus, the aim of this study—which stems from a real case in which it was of paramount importance to diagnose a portion of what looked like a gunshot wound (a semicircular lesion on badly charred bone) as indeed a gunshot wound—was to perform both a "qualitative test" on the detectability of radiopaque metallic residues in badly charred bone and a "quantitative test" on the amount of residues remaining after the exposure to very high temperatures using two kinds of samples (bone with and without soft tissues), two kinds of projectile ("full metal-jacketed bullet" and "unjacketed lead bullet"), and one kind of radiological technique, namely digital radiography (DR)—simple, cheap, and user friendly. Unjacketed bullets seem to leave much more radiopaque material when traveling through tissues [24], and radiography allows an accurate assessment of bone tissues, especially when images are observed at high magnification. In charred material it is at times common to find lesions which may look like a gunshot wound but may not be. This may be the result of the different processes the tissues undergo during the exposition to high temperatures, and certifying whether these metallic residues survive and how even at 800°C is crucial for verifying the utility of a standard X-ray analysis in such cases.

The large majority of research concerning the detection of metal residues refers to bodies in a good state of preservation and case reports—badly preserved samples, such as charred or putrefied samples, have not been systematically studied. Thereby, at the moment, very little literature exists on the survival of metal residues in charred material [25–29].

Materials and methods

Animal models

Thirty-one adult bovine ribs, with a length ranging from 20 to 27 cm and a thickness ranging from 2 to 5 cm, were used for this study: for 15 of the soft tissues, mainly muscle, were preserved—these samples were named “dressed” (“D”), whereas for the other 16 the soft tissues were stripped away. These ribs were named “naked” (“N”). Samples were taken from local abattoirs where the animals were killed for alimentary purposes.

Weapons and projectiles

Each rib was shot at the firing grounds of Pavia, and the weapon chosen was a “Beretta type 98 FS” (series 92) caliber 9 mm. Two kinds of projectiles were used, namely “Magtech-cbc” LRN projectiles (with unjacketed lead bullets) and “Fiocchi” 123 projectiles (with full metal-jacketed bullets).

Every sample was shot with a single projectile, at a near-contact range, producing a clearly visible gunshot wound in each sample. In summary four groups were obtained: (1) from no. 1 to no. 9: NF (naked rib, full metal-jacketed bullet), (2) from no. 10 to no. 16: NL (naked rib, lead unjacketed bullet), (3) from no. 17 to no. 24: DF (dressed rib, full metal-jacketed bullet), and (4) from no. 25 to no. 31: DL (naked rib, lead unjacketed bullet). Each sample was individually placed in a plastic bag and stored in a freezer before and after the radiological trials.

“Charring cycle”

In order to simulate severe human body combustion, all samples underwent a “charring cycle” in an electric oven. The oven was a “Vega s.r.l.,” model “Vega 150,” with a capacity of 150 l, which reaches a maximum temperature of 1,280°C, with a rating of 10.0 kW and a tension of 230–400 V. The complete cycle lasted 24 h: in the first 12 h, the samples were heated to a temperature of 800°C, for the remaining 12 h they were left to cool once the oven was turned off. Every sample reached the morphological features of “calcined bone” (Fig. 1) with complete loss of soft tissues. Previous experiments showed as benchmark temperatures for bone’s carbonization and calcination, respectively 400°C (“black bone”) and 800°C (“white bone”).

Radiological analyses

DRs were performed before and after the charring process, in an anteroposterior projection. DRs were performed with a triple-phase X-ray tube with fixed plant and rotating anode (power 72 kV, inherent filtration 3.5 mm of Al) with a double localized spot (1.2×1.2 mm and 2×2 mm) and a distance of 100 cm from fire to film. Radiographs were analyzed, looking for and counting the presence of metallic radiopaque residues, indicative for the presence of radiolucent residues, and comparing the number of these residues before and after the burning process.

Results

Table 1 shows, in a numerical form, the results obtained from the search of metallic residues in radiographs, identified as roughly spherical, markedly radiolucent

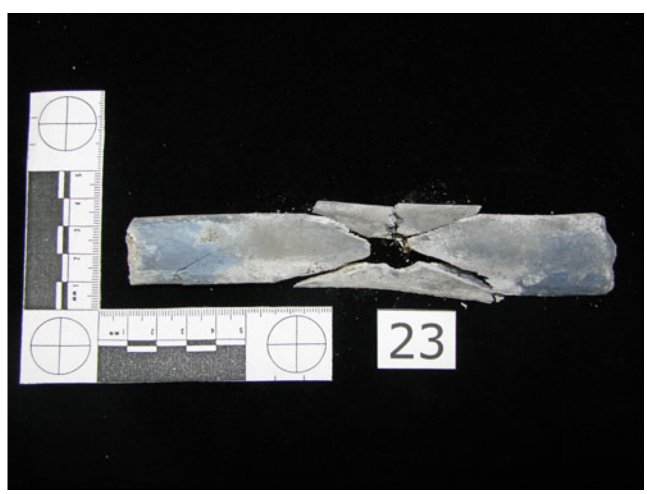

Fig. 1 Appearance of a “dressed” rib after the charring cycle

Table 1 Radiographic findings regarding the number of residues found before and after the charring cycle

Type	Sample	Radiopaque residues in radiographs		
		"Fresh" rib	Charred rib	Concordance fresh/charred (%)
NF	1	1	1	100
	2	4	0	0
	3	2	1	50
	4	8	3	24
	5	2	1	50
	6	8	2	25
	7	3	0	0
	8	7	4	57
	9	3	1	33
NL	10	3	3	100
	11	6[a]	3	50
	12	10[a]	3	30
	13	7[a]	5	71
	14	7[a]	2	29
	15	4[a]	3	75
	16	10[a]	5	50
DF	17	5	0	0
	18	5	1	20
	19	10	1	10
	20	10	6	60
	21	8	3	37
	22	3	1	33
	23	2	0	0
	24	3	1	33
DL	25	7[a]	0	0
	26	10[a]	0	0
	27	10[a]	3	30
	28	10[a]	5	50
	29	10[a]	9	90
	30	10[a]	0	0
	31	10[a]	2	20
Category	Number of residues		Category	Number of residues
0	0		6	From 15 to 19
1	1 or 2		7	From 20 to 25
2	3 or 4		8	From 25 to 30
3	From 5 to 7		9	From 31 to 35
4	From 8 to 10		10	Over 35
5	From 11 to 14			

NF naked rib, full-jacketed bullet, *DF* dressed rib, full-jacketed bullet, *NL* naked rib,unjacketed lead bullet, *DL* dressed rib,unjacketed lead bullet

[a] Many residues localized around the wound's margin

residues. First of all, one can note the consistent decrease in the number of residues when the sample is badly charred. Globally, at least one residue was found in 24 cases out of 31 analyzed, with a 77% survival rate after combustion, thus even after the exposure and fragmentation. Moreover, more residues were found in samples shot with the unjacketed bullet ("L" samples), reaching 100% of cases when analyzing "NL" charred ribs (Table 2). The chances of finding these kinds of residues after the burning process seem to be higher in "naked" ribs (without soft tissues) rather than in "dressed" ribs (with soft tissues). The mean category (Table 3) of residues is always greater in samples with soft tissue around the bone ("DF" and "DL" type) compared to samples with only osseous tissue ("NF" and

Table 2 Percentage of cases with residues after charring

Category	Percent
NF	78
NL	100
DF	75
DL	57
N (NF+NL)	88
D (DF+DL)	67
F (NF+DF)	76
L (NL+DL)	79
TOT (total mean)	77

"NL" type). Belonging to one of these two categories (with or without soft tissues) seems no longer relevant when evaluating the charred samples, where 800°C reached with the charring cycle led to the disappearance of soft tissues, leaving only the calcined bone. Furthermore, more residues are found in samples shot with unjacketed bullets, both before and after burning. In fact, the mean number of residues are always higher when the observed ribs are of the "L" type (shot with the lead unjacketed bullet), especially when there is soft tissue around the bone ("D" ribs). Moreover, in the "L" samples, residues on the margins of the gunshot wound (Fig. 2) were found in 100% of cases when looking at the fresh ribs, and in most cases when analyzing charred samples (in 100% of "DL" fresh samples, and in 80% of "DL" charred ribs; Fig. 3). These features were not found in "F" ribs (shot with the full metal-jacketed bullets), where metallic residues in the wound area were found only in 56% of "NF" and in 50% of "DF" fresh samples. Especially in charred samples, residues were detected only in 33% of "NF" charred samples, and in 0% of "DF" charred samples. Other interesting characteristics concern the wound's perimeter: if in "F" ribs little or no residues were found in most cases

Table 3 Mean categories and concordance concerning the number of residues

Type	Mean categories		Mean concordance fresh/charred (%)
	Fresh	Charred	
NF	4.22	1.44	38
NL	6.71	3.42	58
DF	5.75	1.62	24
DL	9.57	2.71	27
N (NF+NL)	5.31	2.31	48
D (DF+DL)	7.53	2.13	26
F (NF+DF)	4.94	1.53	31
L (NL+DL)	8.14	3.07	43
TOT[a]	6.39	2.23	37

[a] Total mean

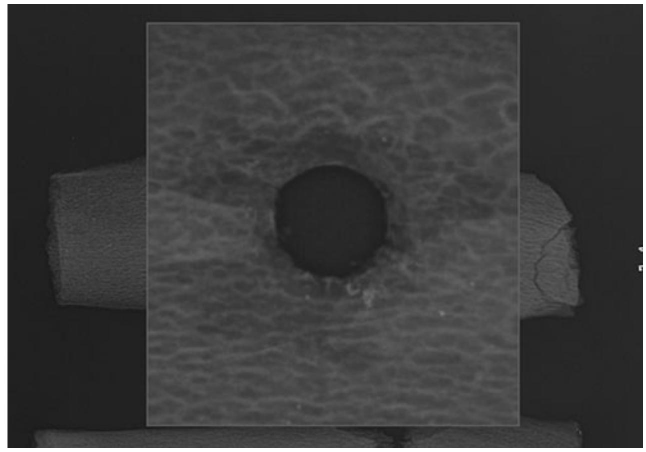

Fig. 2 Residues on the margins of the bullet wound in a "fresh" rib shot with the unjacketed bullet

(Fig. 4), both in fresh and charred samples, several residues were found in "L" fresh ribs, assuming the pattern of a "cloud" of residues, clearly evident especially in fresh ribs with soft tissues (Fig. 5). This pattern is no longer observed in charred ribs, even though in the vast majority of cases a certain number of residues could be still detected (Fig. 6). The "concordance" values shown in Table 1 were obtained from the ratio between the number of residues detected before and after charring. The observation of the mean concordances shown in Table 3 underlines the highest values in the comparison between fresh and charred samples belonging to the "N" and "L" categories.

Discussion

In real cases of charred human remains, where, for example, the victim has been shot and then burnt, not always does the gunshot lesion appear as a round lesion with a beveled margin. Sometimes, because of fragmentation and splintering, we are left only with a part of the entire circumference and not much more; in these cases, the diagnosis of a gunshot wound cannot be performed only on the basis of morphology, but other parameters must be taken into account such as chemistry and radiology.

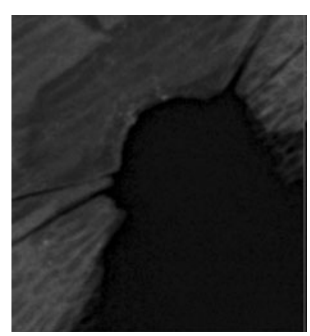

Fig. 3 Residues on the margins of the bullet wound in a charred rib shot with the unjacketed bullet

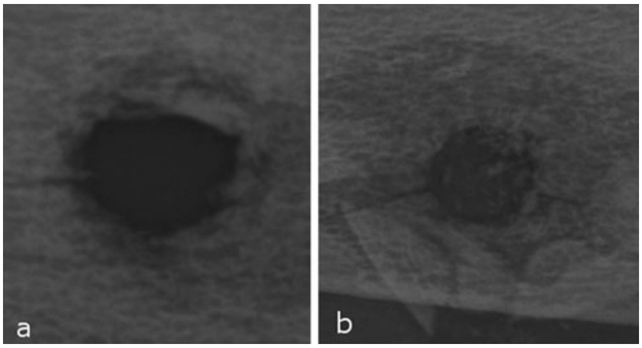

Fig. 4 **a** Lesion produced by the full metal-jacketed bullets in a "naked" rib: no residues on the margins. **b** Lesion produced by the full metal-jacketed bullet in a "dressed" rib: no residues on the margins

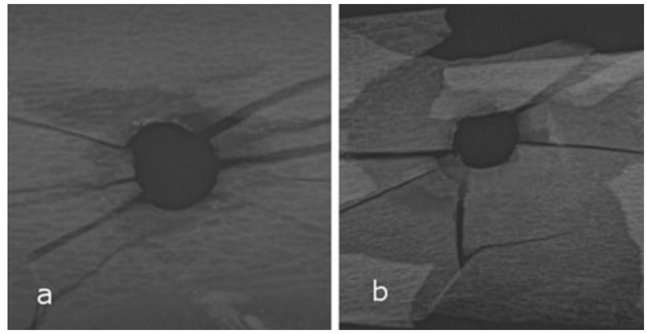

Fig. 6 **a** Decrease in the residue number after the charring process (same rib shown in Fig. 5a). **b** Effects of the charring process in the same rib shown in Fig. 5b: the "cloud" is no longer visible

However such cases are frequently regarded as hopeless. Examiners sometimes suppose erroneously that severe degradation due to the flames may have destroyed all residues which could help in the diagnosis: no study has ever focused on the survival and visibility of such residues by radiology (a simple, cheap, and user-friendly method) in charred remains. This led the authors to perform the present study. The actual identification of a gunshot wound may be very difficult to perform macroscopically (e.g., it can be difficult to verify whether a fragment is part of a lesion or not). Many groups have studied the features of gunshot wounds with radiological investigations using many kinds of techniques [11–18, 21, 22, 30–36] but never systematically in charred bone.

The study aimed at creating a condition of severe morphological alterations of the samples (fragmentation, etc.), making it difficult to perform a macroscopical analysis, and evaluating consequently, with the radiological search of metallic radiolucent residues, if a gunshot wound or at least the passing of a projectile could be detectable. Radiographs proved their usefulness in achieving this goal, especially in the search for the survival of residues. In a global decrease in the total number of residues, due probably to cracking and splintering of the bone and the melting and/or volatilization of metals, radiographs made it possible to find metallic residues, even after the charring process in most cases (in another study these, will be examined chemically by SEM EDX analysis). We assume that this radiopaque material was left by the projectile (e.g., Pb, Sb), by the jacket (Zn and Cu), by the primer, or by material expelled from the barrel as metallic residues. Some metals contained in these compounds were carried beyond their melting points (e.g., Pb at 327°C, Sb at 630°C) and some not (e.g., Cu at 1984.6°C), although even completely molten metals should be radiologically detectable. In the analysis of fresh samples, X-rays showed the highest sensitivity in the detection of metallic residues when analyzing samples with soft tissues, more likely to retain this kind of particles than bone, and when analyzing gunshot wounds created by unjacketed bullets (probably because of the absence of the jacket, which causes an increased release of residues when the bullet hits the bone). The number decreases in burned samples—but residues survive nonetheless. In particular, bone seems to better retain residues during exposure to high temperatures (as documented by the highest percentages of residues in naked charred ribs and by the mean concordances reached in "N" ribs—Table 3). Probably, a large proportion of residues found in soft tissues, given the greater ability of the latter to retain residues when the material is fresh, is lost with carbonization, whereas residues already present in bone persist even at extreme temperatures. Furthermore, a very interesting phenomenon was noticed: for unjacketed bullets, radiographs showed a considerable number of radiolucent residues on the margins of the bullet wound, and many times, this pattern was maintained even after the charring cycle. This could be of primary importance when the gunshot wound is macroscopically unrecognizable. The highest mean concordance values reached when the bullet used was of the unjacketed type and is probably due simply to the greater number of residues left in the tissues.

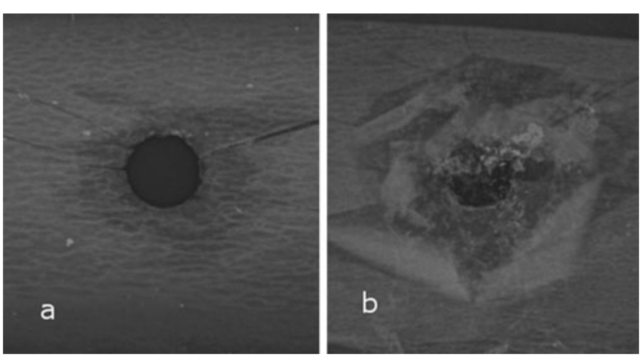

Fig. 5 **a** Presence of many residues around the wound's margins ("NL" fresh rib). **b** "Cloud" of residues around the lesion ("DL" fresh rib)

This study proves the survival of gunshot metallic residues in charred bone but poses further questions: first of all, the temperature of 800°C left the samples with no soft tissue. It is assumed, however, that in reality, when a corpse undergoes a burning process, the temperature reached is likely to maintain a certain amount of soft tissue, allowing for the identification of a greater number of residues compared to calcined bone with no soft tissues. Furthermore, standard radiography is unable to distinguish between metal residues and other residues, such as glass or soil: in this study, the particular handling of the samples allowed us to ascribe radiopaque residues found to metallic residue directly related to the gunshot, but in a real situation the contamination by environmental agents may be problematic. Furthermore, as shown in this study, the recognition of a gunshot wound may be more difficult if the projectile used is of the full metal-jacketed type: in fact, this kind of projectile leaves less residues in the tissues, making it more difficult to precisely locate the wound. We deduce from these observations that radiography can help in the research of metallic residues and therefore in the diagnosis of gunshot wounds and that more advanced investigations (like CT or MRI) and SEM-EDS could provide further assistance in forensic analysis. More importantly however, although more research needs to be performed, the study has proven that gunshot residues frequently survive extreme charring processes.

Acknowledgments We thank Mr Giancarlo Scarpa and the staff of the firing ground of Pavia for their collaboration during the experiment and the butchery of Parma for the bovine ribs.

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