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Detachment of the periosteum and soot staining of its underside in contact shots to the cerebral cranium

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Abstract Contact gunshot wounds are usually characterized by a muzzle imprint, a powder cavity (“pocket”), the presence of carboxyhemoglobin and often also stellate tears of the skin radiating from the bullet entrance hole. In shots to the cerebral cranium an additional sign may be observed around the bone defect: the periosteum is detached and reflected with soot on the underside. The frequency and possible causes of these periosteal findings are discussed on the basis of 68 contact gunshot wounds from forensic autopsy material and experimental shots fired against the frontal bone of a slaughtered calf.

Keywords Contact gunshot wound · Cerebral cranium · Powder cavity · Periosteum · Soot staining

Introduction

Contact gunshot wounds to the head show special features resulting from the anatomical conditions and the combustion gases expanding under the skin [10, 16, 20]. The morphological diagnosis of a contact shot is usually made on the basis of the following signs: muzzle imprint [24], “powder cavity” (pocket-like undermining) [11, 23], often accompanied by the formation of carboxyhemoglobin [3] and under certain conditions also stellate laceration of the skin. Nevertheless, there may be cases with atypical and misleading entrance wounds in contact shots to the head [14, 25]. So it seems justified to address this important subject of forensic wound ballistics again by presenting an additional morphological sign.

Dedicated to Prof. Dr. Dr. h.c. B. Brinkmann on the occasion of his 65th birthday.

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In a contact shot to the cerebral cranium the powder gases penetrate into the depth of the entrance wound, so that soot and other gunshot residues may be found in the subcutaneous pocket under the scalp, on the margin of the perforated bone [2, 6, 9] and on the dura mater [3, 9]. In this context Spitz [22] wrote: “Gunsmoke is often deposited on the bone after the periosteum has been elevated by the gas pressure”.

According to our experience (first presented in 1999 at the 8th Spring Meeting of the German Society of Legal Medicine) soot soiling may not only be visible on the bone, but also on the underside of the detached periosteum. This subperiosteal soot soiling is regarded as a significant detail which has not been given sufficient attention in the medical literature so far [17, 18]. The purpose of the present paper is therefore to emphasize the importance of this “periosteal sign” by analyzing relevant gunshot fatalities from the autopsy practice.

Materials and methods

Autopsy cases

The study material comprised 65 forensic autopsies performed from 1992 to 2004 on victims with contact shots to the neurocranium. There were 68 entrance wounds in total, localized as follows: right temple 41, left temple 6, forehead 15, lateral part of the parietal bone 2, and vertex 4.

The weapons used were 57 handguns (pistols of .22 cal. rimfire, 6.35 mm, 7.65 mm, 9 mm Luger; revolvers loaded with cartridges .32 Auto, .357 Magnum, .38, .38 Special, .45 ACP), 1 rifle for Flobert cartridges 9 mm, 4 rifles of .22 cal. rimfire, 4 centerfire rifles (cal. 7.5×55 mm, 7.62×39 mm, 8×57 mm). The ammunition used included cartridges with jacketed and lead bullets.

Altogether there were 60 suicides (with 61 bullet entrance wounds) and 5 homicide victims (showing 7 contact shots). The entrance sites in the 5 homicide cases

were: vertex (1) [4], forehead (2), right parietal region (2) and left parietal region (2).

The medicolegal investigation of the victims was performed according to the usual recommendations [2, 3]. The scalp was incised transversely avoiding the wounds and the epicranial aponeurosis was carefully removed from the periosteum so that the original findings around the bony entrance hole could be inspected and documented photographically. Then the periosteum surrounding the bone defect was incised radially [22] to demonstrate the peripheral extension of periosteal detachment. Subsequently, the skull cap was severed with an electric saw at some distance from the bullet holes. In 5 exemplary cases a small bone plate from the bullet entrance site with the adherent periosteum was removed, fixed in 4.5% formalin, decalcified with EDTA, embedded in paraffin, cut in a microtome and stained with hematoxylin-eosin.

Experimental shots

Experimental contact and distance shots were fired under identical technical conditions against the shaved forehead of a slaughtered calf. The weapon used was a self-loading pistol, Walther P38, cal. 9 mm Luger, with cartridges from Dynamit Nobel (full metal-jacketed bullet with round nose, mass 8 g, Vo~340 m/s and Eo~490 J). The entrance sites were located in the right or left frontal bone and the

range of fire was 2 m for the distant shot. After inflicting the gunshot wounds, the soft tissues of the head were dissected in layers.

Results

Autopsy findings

In 65 (95.6%) of the 68 contact shots to the cerebral cranium (temporal, frontal and parietal regions) the periosteum was detached around the bullet entrance hole and torn radially. The flaps of the elevated periosteum were folded back, so that the underside of the periosteum, which had originally been in contact with the bone, was now turned outwards. It was blackened by soot just as the exposed outer table surrounding the bone defect. The blackened margin of the bony entrance hole was often even discernible in the depth of the entrance wound before dissection of the scalp (Fig. 1a). The underside of the detached periosteum was covered by soot over an area varying between 1–10 mm in width (Fig. 1b, c) and the smoke staining was either concentric or eccentric. Detachment and soot soiling of the periosteum were even observed in shots from .22 cal. rimfire weapons.

Around the central zone of periosteal detachment, there was sometimes a peripheral, up to 3 cm wide zone in which the periosteum was lifted, but not folded back. The area of periosteal separation from the bony surface was

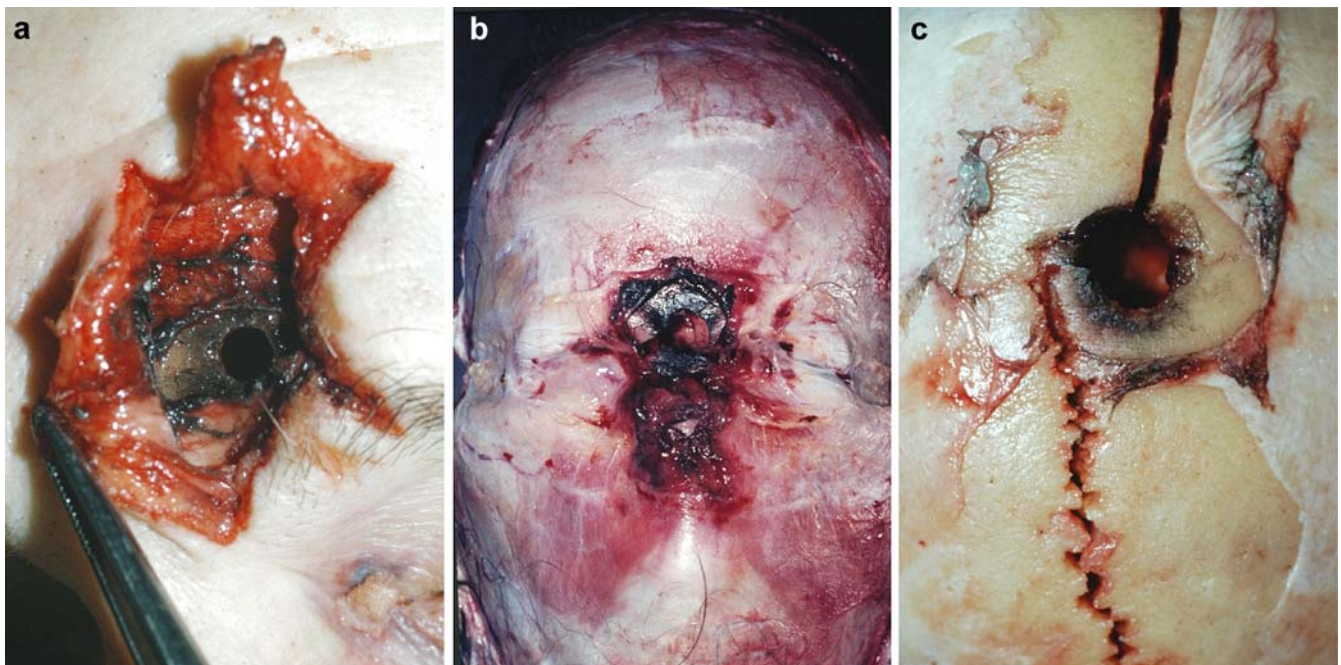


Fig. 1a-c Macromorphological findings in contact gunshots to the cerebral cranium. **a** Stellate entrance wound in a homicidal contact shot to the forehead (above the nose). The weapon used was a pistol of caliber .22 lr. Soot staining of the outer table, which is exposed around the bullet hole. The periosteum is detached, with its blackened underside turned outward. **b** Frontal aspect of the skull after dissection of the epicranial soft tissue. Entrance hole in the frontal bone from a suicidal contact shot with a pistol of caliber

7.65 mm. Soot staining on the outer table and on the underside of the periosteum, which is turned outward. **c** Contact shot in the parietal region inflicted with a pistol caliber 7.65 mm (homicide) [4]. View of the entrance site after dissection of the epicranial layers. The bullet hole is surrounded by a semi-circumferential zone of soot staining. The adjacent periosteum is detached and blackened on its underside

limited in some cases by the anatomical conditions (e.g. cranial sutures). Consequently, the large flat bones, as in the parietal and frontal region, were preferred sites of extensive elevation of the periosteum. Towards the peripheral parts of periosteal detachment the outer table did not show homogenous blackish-gray soot soiling, but individual particles of gunshot residues could be found, even in the angle between the bone and the elevated periosteum. Parts of the detached periosteum and the peripherally adjacent border area were colored red from suffusion with blood (cf. Fig. 1a, b).

Under certain conditions the detachment and soot soiling of the periosteum was less pronounced: in loose contact wounds, in cases with uneven entrance sites (e.g. auricle), in regions with thick layers of soft tissue (e.g. temporal muscle) or in contact shots from weapons with a prolonged decompression of powder gases (e.g. due to silencers, flash suppressors and additional openings on the barrel [7, 8]).

Soot blackening of the periosteum was completely absent in the following 2 cases in our study material:

- A contact shot to the temple with ammunition caliber .22 Short where neither detachment nor soot blackening of the periosteum was seen.
- A suicide victim who had fired 2 contact shots to his forehead with Flobert cartridges and the periosteum of the frontal squama was slightly detached, but as expected not soiled with soot, as Flobert ammunition contains only primer and no propellant [19].

Histological findings

Histological examination of the periosteum from the entrance sites (Fig. 2a–c) revealed extensive deposits of amorphous, blackish gunpowder residues on the underside of the elevated periosteum, whereas the former upper surface was unaffected. Under the peripheral parts of the detached periosteum minor quantities of soot together with partly burned powder particles were found. In the adjacent border area where the periosteum resumed contact with the outer table of the bone there was a circumferential ring of (sub)periosteal bleeding.

Experimental shots

In the contact shot to the calf's forehead the entrance hole in the frontal bone was surrounded by large amounts of soot deposited on the outer table to a width of 2–5 mm (Fig. 3a). The periosteum was detached from the bone in a diameter up to 70 mm. The underside of the elevated periosteum showed intense soot staining around the central perforation (width 3–10 mm) and disseminated individual powder particles in the periphery.

In the shot fired from a distance of 2 m (Fig. 3b) there was a 2–4 mm wide circular detachment of the periosteum

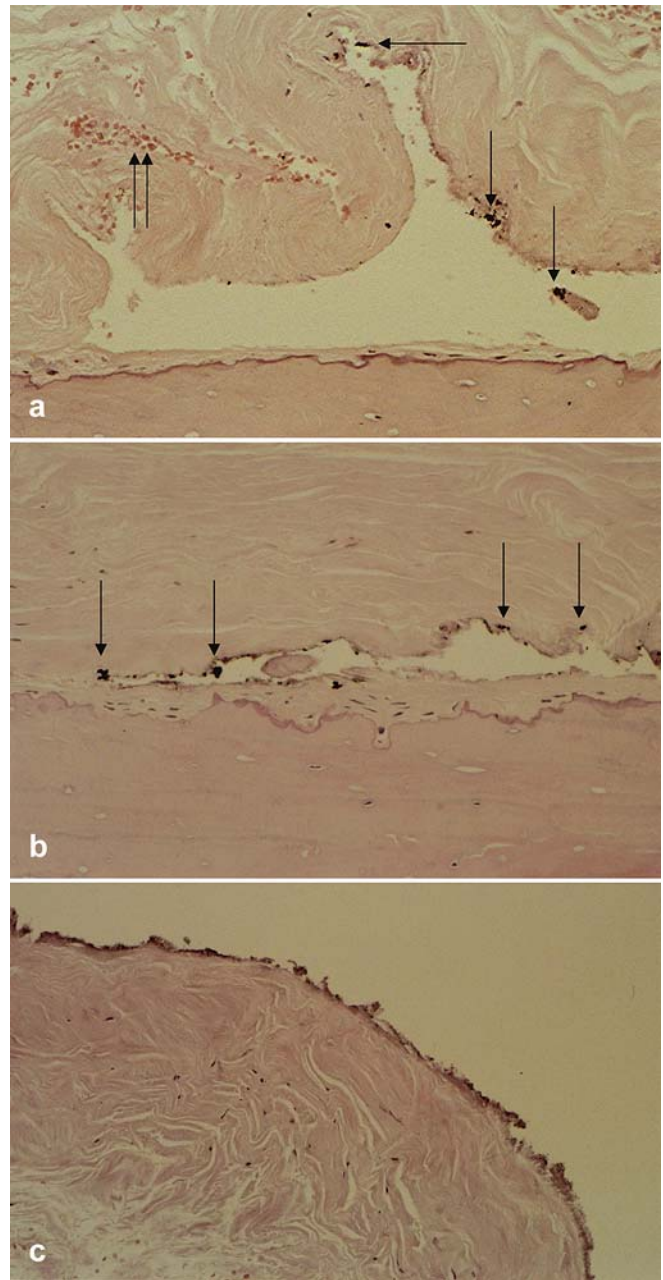


Fig. 2a-c Histological findings close to the bullet entrance hole in the outer table (contact shots to the temple), staining with hematoxylin-eosin. **a** Detached periosteum (*upper half*) and outer table of the skull (*bottom*) separated by a gap containing black gunshot residues (*single arrows*); extravasations of blood in the periosteal tissue (*double arrows*), 160 \times . **b** Peripheral angle of the narrow space between the elevated periosteum (*upper half*) and the underlying outer table with blackish gunshot residues (*arrows*), 200 \times . **c** Reflected flap of detached periosteum with a thin layer of gunshot residues deposited on the former underside, 200 \times

around the bullet entrance hole, but the underside of the elevated periosteal margin was not covered by soot.



Fig. 3a-b Experimental shots to the forehead of a slaughtered calf. **a** Entrance site (contact shot) after dissection of the epicranial soft tissues. Circular zone of soot staining around the bullet hole in the bone. Extensive detachment of the periosteum with soot blackening on the underside now turned upward. **b** Entrance site (distant shot). Narrow zone of periosteal detachment around the entrance hole in the bone without deposition of soot

Discussion

The analysis of 68 contact shots to the neurocranium revealed that in 95.6% the following specific changes concerning the periosteum around the bony entrance hole could be observed:

- Circular detachment of the periosteum from the outer table typically in combination with hemorrhagic imbibition of the affected periosteal tissue;
- Radial tears of the elevated periosteum with flaps facing outward;
- Soot soiling and deposition of gunpowder particles on the exposed underside of the periosteum.

The above changes as a whole including soot staining of the periosteum, can be attributed to the powder gases which expand under the scalp overlying a flat bony surface when a contact shot is fired [5]. On the other hand the experimental distance shot to the skull of a calf shows that

the bullet alone may be able to produce a small collar of periosteal detachment, but without deposition of soot. This latter finding has been observed in earlier test shots from a distance of 30–40 cm to flat bones covered with soft tissue: a narrow collar of the periosteum was similarly detached without any soot staining of its underside [15]. As the bullet perforates the entrance region, the tissue is radially accelerated and displaced centrifugally causing shearing forces between the consecutive layers [19]. This behavior also explains the marginal separation of the periosteum from the underlying bone in distant shots.

The morphological entity described and subsumed under the term “periosteal sign” is seen in a large majority of contact shots to the cerebral cranium. The muzzle gases are obviously able to separate the periosteal layer from the underlying bone, as they expand within the soft tissue. By the same mechanism soot and powder particles are also deposited on the underside of the elevated periosteum and on the uncovered outer table of the bone.

In contact shots to the head, the presence of gunsmoke on the bony circumference of the entrance hole had already been mentioned by Haberda in 1893 [9]. By layer-wise dissection of the epicranium we could demonstrate that soot is also deposited on the underside of the detached and reflected periosteal flaps. The undermining of the periosteum may exceed the area of intense soot soiling by a few centimeters. However, in these peripheral parts the periosteal surface does not show homogenous soot blackening, but dispersed gunshot residues, similar to the scattered deposits which are seen on the surface of the entrance site in close-range shots [12].

A morphological analogue corresponding to the periosteal sign was described by Sigrist in 1984 [21]: in contact shots to human skin there was detachment of the epidermis along the outline of the muzzle imprint with epithelial flaps reflected outwards and blackened by soot on the former underside and the marginal recesses under the lifted horny layer contained gunshot residues. In contact shots to friction skin (palmar or plantar region) the thick stratum corneum is peeled off with intraepithelial deposition of soot [13].

Soot blackening in the depth of a contact wound may be identified for a relatively long time after the incident, sometimes even on macerated skulls [1, 6]. Spitz found deposits of gunsmoke in a cranial gunshot entrance wound after a survival time of 3 months [22]. Referring to our own study material, 3 victims of suicide with gunshots from .22 caliber rimfire weapons had survived the gunshot injury by 2 and 3 days, respectively and showed positive findings of gunsmoke both on the underside of the periosteum and on the bone.

If no soot deposits are detected after a contact shot to the head, the question arises whether this is due to the primary absence of gunsmoke or a secondary loss of traces. For example the shot may have been fired using Flobert cartridges, which do not contain a propellant. Cartridges with small amounts of powder (.22 Short, 6.35 mm Auto) may cause only minor deposits of soot within the entrance wound [3, 19], although in our study

cases there was more or less intense subperiosteal soot blackening even in most shots with .22 cal. rimfire ammunition except one case in which a .22 Short cartridge was used. Berg and Kijewski [1] reported a gunshot fatality in which traces of gunsmoke could no longer be detected after the soot-blackened bone had been stored in an anhill. Di Maio [3] recommended looking for the presence of soot or powder particles in the subcutaneous tissues also in decomposed bodies, preferably with the help of a dissecting microscope.

The evaluation of the 65 autopsies performed on gunshot victims and the results of our experimental shots show that in contact shots to head regions with underlying flat bones it is usually possible to find soot blackening not only on the bony margin of the bullet hole, but also on the reflected periosteal flaps around the entrance defect. So the presence of this “periosteal sign” is a common and significant feature to prove a contact shot to the neurocranium.

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