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ORIGINAL ARTICLE

A patterned abrasion caused by the impact of a cartridge case may simulate an atypical muzzle imprint mark

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Abstract In contact shots, the muzzle imprint is an informative finding associated with the entrance wound. It typically mirrors the constructional components being in line with the muzzle or just behind. Under special conditions, other patterned skin marks located near a gunshot entrance wound may give the impression to be part of the muzzle imprint. A potential mechanism causing a patterned pressure abrasion in close proximity to the bullet entrance site is demonstrated on the basis of a suicidal shot to the temple. The skin lesion in question appeared as a ring-shaped excoriation with a diameter corresponding to that of the cartridge case. Two hypotheses concerning the causative mechanism were investigated by test shots: - After being ejected, the cartridge case ricocheted inside a confined space (car cabin in the particular case) and secondarily hit the skin near the gunshot entrance wound. - The ejection of the cartridge case failed so that the case became stuck in the ejection port and its mouth contacted the skin when the body collapsed after being hit.

Keywords Gunshot injury · Muzzle imprint · Cartridge case · Ricochet · Kinetic energy · Failure of cartridge case ejection

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Introduction

The correct assessment of gunshot injuries is still a challenge both in clinical and forensic medicine [1, 2]. Wound morphology shows considerable variations due to a great number of influencing factors such as type of weapon and ammunition, range of fire, affected body region, prior perforation of an intermediate target, and many others. Knowledge is therefore still incomplete even after many years of vocational practice. To correctly interpret the diverse findings, it is important to train the "diagnostic eye" [3] and to learn from the expert knowledge described in the relevant literature.

The classification of gunshot entrance wounds according to the range of fire is of crucial importance when examining firearm injuries. The diagnosis of a contact shot is usually based on the following characteristics [4]: (1) presence of soot and gunpowder particles in the depth of the wound, often forming a so-called "pocket" and associated with bright-red discoloration of blood/muscle tissue due to carbon monoxide; (2) star-shaped ("stellate") appearance of the entrance wound caused by the subdermal expansion of the powder gases (facultative sign, mainly to be observed in body regions overlying a bony support); (3) patterned pressure abrasion around the entrance hole called "muzzle imprint."

The significance of barrel markings remained unnoticed until this phenomenon was described by Werkgartner for the first time in 1922 [5, 6]. He realized that its shape often allows drawing conclusions as to the contours of the weapon's muzzle and adjacent constructional components. In experimental studies, Hausbrandt [7] and Elbel [8] could demonstrate that the entrance site balloons backward against the muzzle due to the expansion of the inrushing combustion gases, so that the muzzle plane or its contours are imprinted on the skin [9, 10]. After a certain "drying period," the patterned abrasion tends to parch. Muzzle imprint marks may occur also in contact shots

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with blank ammunition [11], as the underlying mechanism is not related to a bullet but to the expanding powder gases.

Apart from the muzzle, some other elements of the weapon such as the front sight, its socket and any guard as well as the recoil spring guide may be imprinted. The same is true for folded shoulder stocks in contact shots from submachine guns [12] and for ramrods in black powder pistols [13]. The marks from such additional components, particularly their location in relation to the gunshot entrance hole, can indicate how the weapon had been held at the time of discharge (in usual, twisted or inverted position [4, 14, 15]). Considering the great diagnostic importance of muzzle imprint marks in contact shots, it seems justified to report on a potentially misleading finding which may be seen in close proximity to the entrance wound, namely a pressure abrasion from the cartridge case.

Case history

A 74-year-old man was found dead on the front seat of his passenger car. The upper part of the body was leaning to the right so that the head came close to the center console (Fig. 1a). A Walther PPK pistol was lying on his lap. A 7.65-mm Browning cartridge case (Geco) was located on the right half of the driver's seat (Fig. 1b, inset). A bullet could not be discovered at the scene.

It was known that the victim had financial problems and his wife suffered from advanced dementia. The objects to the right of the victim were covered with blood spatter, excluding the possibility of someone sitting on the passenger seat when the gun was fired.

Weapon

The Walther PPK pistol (Fig. 2) is a straight blowback-operated semi-automatic weapon. The 7.65-mm Browning cartridge is weaker than the widely used 9-mm Luger or 45 ACP. Like in many pistols of the lower energy range, the breech is not locked and is only held back by a single spring. Given the low momentum transferred by the exiting bullet, the recoil might easily be empeded by a backward arm movement or by holding the breech with the other hand leading to incomplete or even failing ejection of the cartridge case. Interference with case ejection due to a movement of the hand has been noticed in less experienced or weak shooters and persons under stress with somewhat erratic movements and an improper grip on the gun.

Autopsy findings

The deceased had a length of 169 cm and a body mass of 55 kg.

The right thumb was amputated at the metacarpophalangeal joint level (Fig. 3a). No backspatter or soot deposits were seen on the right hand, but a spray of blood was present on the extensor sides of the left fingers (Fig. 3b).

The right anterior temporal region showed a roundish skin hole with a minimum diameter of about 9 mm (Fig. 4a, rectangle). Radial tears up to 8 mm, and rather uncharacteristic abrasions were seen at the wound edge. A distinct muzzle imprint was not discernible. The depth of the entrance wound was blackened with soot, and the right temporal muscle exhibited bright-red discoloration due to carbon monoxide from the combustion gases. The underlying skullcap showed an oval hole measuring 15 × 11 mm accompanied by an incomplete spider's web fracture and concomitant fractures of the skull base.

A stellate exit wound was located in the left posterior parietal/temporal region. The underlying hole in the parietal bone had a maximum diameter of 8 mm with cone-shaped widening in the direction of the shot. Two radial fractures crossed by a transverse fracture line extended to the base of the skull. The wound path ran slightly upward and backward from the right to the left side. Channel-shaped destruction of brain tissue was seen along its way. Away from the bullet track, no cortical contusions or other intracerebral bleedings were observed. Especially above the left cerebral hemisphere, there was a moderate subarachnoid and subdural hemorrhage.

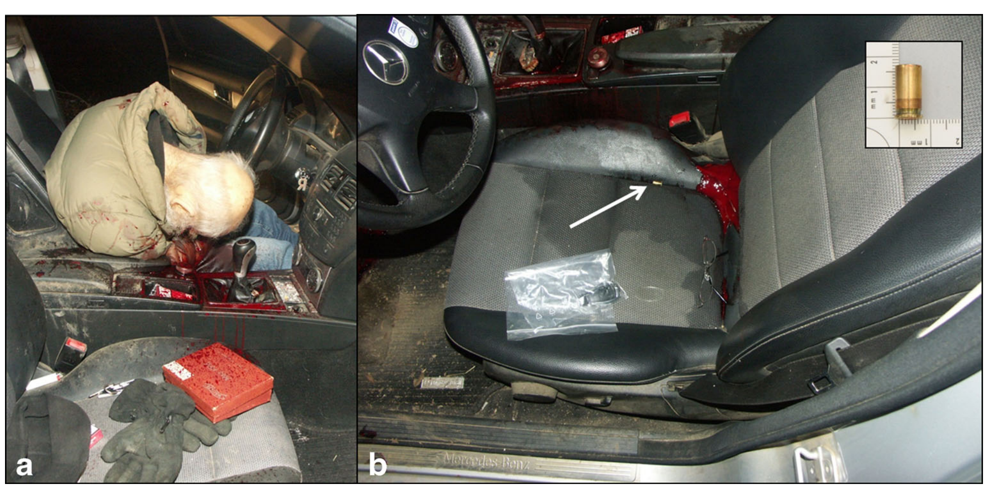

Fig. 1 **a** Suicide scene: A 74-year-old man was found dead inside his car. Note the short distance between the head and the center console. **b** A cartridge case was lying on the driver's seat (*arrow*). *Inset*: close-up view of the cartridge case

Fig. 2 Pistol Walther PPK, cal. 7.65 mm Brown. **a** Lateral view. **b** Muzzle plane

At a distance of about 3 cm from the entrance wound in the right forehead region, a circular excoriation measuring 8 to 9 mm in diameter was located (Fig. 4a, arrow; b). A linear 1.5-cm-long abrasion emanated from the lower margin of that lesion.

At the time of death, the victim was not under the influence of alcohol.

Hypotheses

Due to the circumstances, the involvement of a third party could be excluded. Therefore, it had to be clarified how a self-inflicted gunshot to the temple could cause a patterned abrasion on the forehead. The absence of any corresponding object in the vicinity of the deceased indicated that the weapon system itself must have been responsible for the circular abrasion. The shape and size of the round excoriation matched with the mouth of the preserved cartridge case (Fig. 4c) suggesting that this injury was caused by the impact of the cartridge case. Given the space in the car and the orientation of the gunshot wound, there were only two possible mechanisms allowing the cartridge case to strike the forehead:

1. The ejected cartridge case ricocheted inside the confined space of the car cabin and hit the skin near the gunshot entrance wound.
2. Ejection of the cartridge case failed, so that the case became stuck in the ejection port and contacted the forehead when the unrestrained upper body slumped after being hit.

Experimental design

The abovementioned hypotheses were checked separately. Seven test shots were discharged in order to examine ejection, trajectory and velocity of the cartridge case before and after bouncing against a mechanical barrier. All shots were fired from a pistol Walther PPK, caliber 7.65 mm Browning, using cartridges with full-jacketed bullets manufactured by RUAG Ammotec, Thun, Switzerland (bullet mass 4.7 g, average

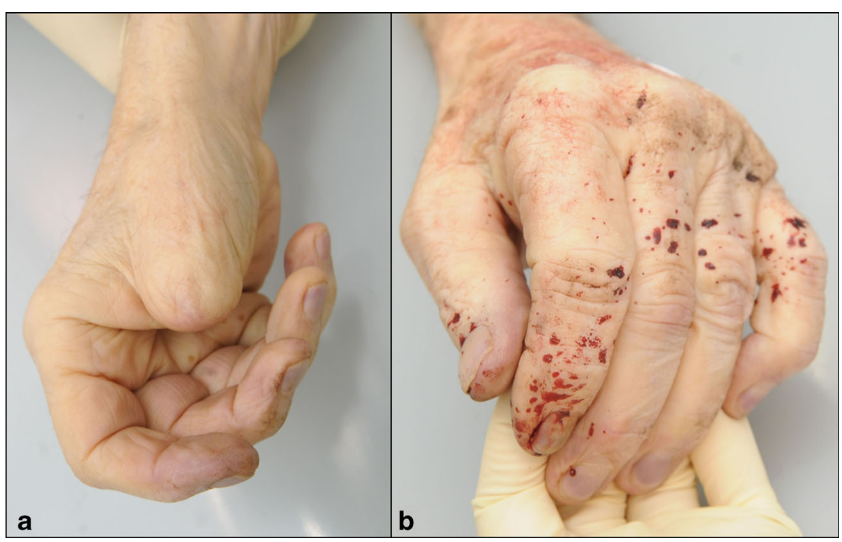

Fig. 3 **a** Right hand. The thumb was amputated at the metacarpophalangeal joint level. **b** Left hand with backspatter on the extensor sides of the fingers

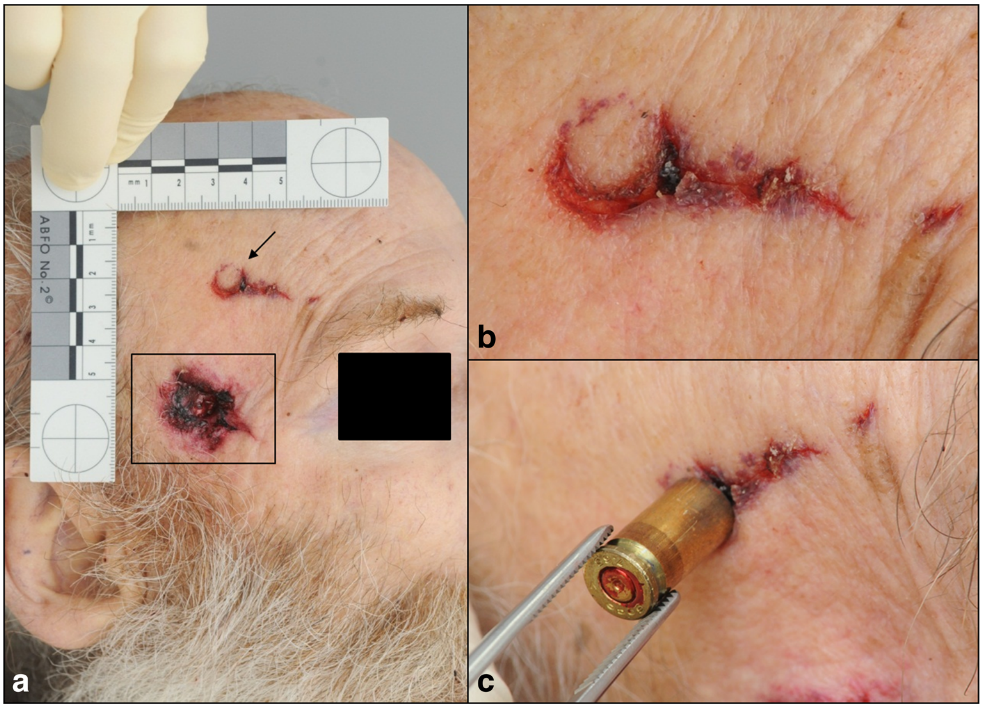

Fig. 4 **a** Entrance wound (*rectangle*) and ring-shaped skin abrasion (*arrow*). **b** Detail of (**a**). **c** Shape and size of the skin lesion correspond to that of the case mouth

muzzle velocity 300 m/s). The average mass of the empty cartridge case is 2.8 g. The cylindrical brass case measures 17.2 mm in length. At the level of the mouth, it has a diameter of 8.52 mm, whereas the base plate is 9.1 mm wide. The ejection port of the pistol is located on the right side.

All test shots were video-documented by a high-speed motion camera (Motion Pro X3™, 1000 fps) from different views (shots 1 and 2: 90° side view; shots 3 and 4: frontal view). Shots 5–7 were fired under a mirror fixed to the upper side of a rectangular framework. The mirror was inclined to the horizontal plane by 45° (Fig. 5). The high-speed motion camera stood behind the shooter so that the ejection plane of the pistol matched the focal plane of the camera. Thus, the trajectory of the cartridge case was recorded from a side view and—by means of the mirror—from a bird's eye view. For shot 7, a steel plate served as a mechanical barrier placed upright inside the framework, representing a ricochet without cushioning. The distance between the pistol and the steel plate amounted to about 25 cm. When shot 7 was discharged, the pistol was held such that the cartridge case hit the plate approximately at a right angle. Measuring tapes were fixed to the bars of the framework to determine the distance covered by the cartridge case and to calculate its speed at intervals of 0.005 s.

Additionally, the wounding potential of free-falling cartridge cases was examined. Metal pipes of different length (0.54, 1.02, 1.56, 2.51 m) were positioned vertically above the forehead of a volunteer lying in supine position. Then, cartridge cases with the mouth pointing downward were dropped through the pipes. The velocity of the cases at the moment of impact was calculated by the formula: $v=\sqrt{2gh}$ (g: gravity acceleration~9.81 m/s^2) and made to match that of the ejected cartridge.

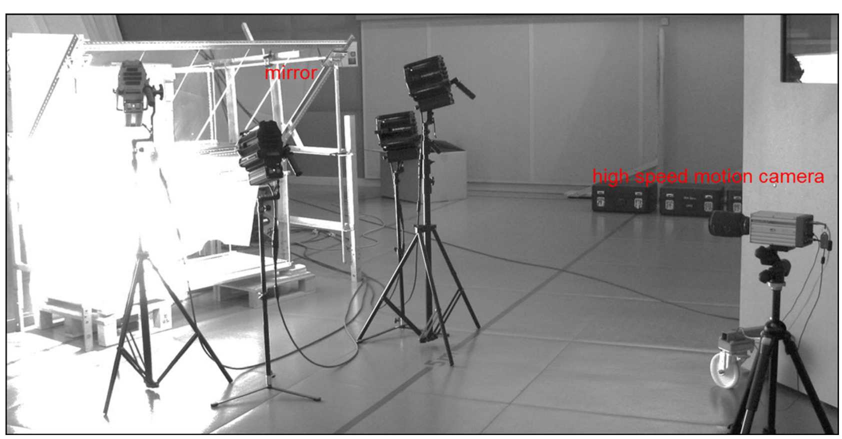

Fig. 5 Experimental set-up

Failure to eject the cartridge has been reported in weaker persons, inexperienced shooters, or when the pistol was not handled correctly. To reproduce this, the following test shots were made:

- First time shooters, male and female
- Shots with the non-dominant hand pulling the trigger with the thumb and holding the rear part of the grip with the 4 other fingers
- Shots with the dominant hand, in which the thumb was not used to hold the grip
- Shots with the dominant hand while the other hand held the slide to steady the position of the pistol

For safety reasons, only a small number of shots were fired under the last-mentioned conditions.

Results

In all video-documented shots, the cartridge cases were ejected orthogonally to the gun barrel and traveled in a slight arc to the right with constant rotation around its transverse axis (Fig. 6).

Before ricocheting, the velocity of the cartridge case amounted to 7.6 m/s in shot 6 and to 5.4 m/s in shot 7. Due to the short distance, the speed loss of the case before ricocheting was negligible.

Test shot 7 was fired to assess the trajectory, velocity, and kinetic energy of an ejected cartridge case after ricocheting. The trajectory of the case after being reflected by the steel plate was approximately orthogonal to its surface and covered a distance of about 25 cm before it struck the shooter's hand. The average velocity was 5.4 m/s before ricocheting and 2.9 m/s afterwards.

Kinetic energy depends on velocity and mass: $E=0.5\times mv^2$ [E]. Accordingly, the kinetic energy of the ejected cartridge case was

$$E = 0.5 \times 0.0028 \text{ kg} \times 5.4 \text{ m/s}^2 = 0.041 \text{ J before and}$$
$$E = 0.5 \times 0.0028 \text{ kg} \times 2.9 \text{ m/s}^2 = 0.012 \text{ J after ricocheting.}$$

As the case was not deformed on impact, no kinetic energy was lost to deformation. The wounding effect depends on the energy density, i.e., the kinetic energy in relation to the impact area ($E'=E/A$). Thus, the energy density of a moving object is determined by the area of impact. Corresponding to the ricocheted case in test shot 7, an energy of E=0.012 J was assumed for the following calculations: When the skin is hit by the base of the cartridge case (diameter, 9.1 mm), the energy density is about 1.85^{-04} *J/mm*^{2} (=0.012 / ($\pi\times4.55^2$)). When the mouth of the cartridge case (thickness at the edge, ~0.1 mm) impacts, the energy density amounts to approx. 4.54^{-03} *J/mm*^{2} (=0.012 / ($4.26^2\pi-4.16^2\pi$)). In our case, the skin abrasion showed a ring-shaped pattern. Therefore, the second scenario seems to be more likely.

Fig. 6 Motion sequence of the ejected cartridge case recorded by high-speed motion camera. Note the rotation of the case around its transverse axis

In the drop impact tests, a 3-mm-long bleeding lesion was observed on the forehead of one volunteer (Fig. 7) with the longest pipe (2.51 m; kinetic energy of the case, 0.043 J). In all other instances, only transient reddening of the skin was seen. In this single case with a bleeding lesion, the energy density at the moment of impact was 0.016 J/mm^2 (=0.043 / ($4.26^2\pi-4.16^2\pi$)), which was still higher than the energy density after ricocheting.

Failure of cartridge case ejection could be reproduced only once, when the shooter used his left hand to steady the pistol. In this constellation, the cartridge case was not ejected but became stuck in the ejection port with its mouth pointing outwards (Fig. 8).

Discussion

In firearm injuries, the occurrence of parched imprint marks is not entirely uncommon also in non-contact shots. When

Fig. 7 Bleeding skin lesion on the forehead of a test person caused by the impact of a case mouth

Fig. 8 Cartridge case jammed in the ejection port

shotguns are discharged from an intermediate distance, wads or plastic cups may cause excoriations of characteristic shape. Weak bullets hitting the skin without penetrating it usually produce a patterned abrasion in combination with local bruising [16, 17]. Depending on the type of the shooting device (e.g., certain livestock stunners), entrance wounds from contact shots may be accompanied by typically arranged soot depositions under which the skin tends to parch and assume a brownish color [18].

The suicide reported here is remarkable because of a ring-shaped pressure abrasion that seemed to be part of the muzzle imprint at first. The circular configuration, the diameter, and the location near the bullet entrance wound initially suggested that the mark had been caused by a constructional part of the suicide weapon. However, the pistol used (Walther PPK) does not possess any component corresponding to the patterned excoriation. Besides, the distance between the center of the stellate entrance wound and the midpoint of the parched circle (3.7 cm) seemed too large compared with the structural elements of the muzzle plane. Therefore, another mechanism had to be considered. Some aspects suggested that the roundish skin mark was due to the impact of the cartridge case: The size and shape of the case mouth matched the circular imprint mark. The scratch-like excoriation directly next to the ring-shaped mark indicated that the causative blunt force had also been exerted tangentially in a scraping manner.

Two hypotheses as to the causative mechanism were examined by experimental shots:

1. *Impact by a ricocheted cartridge case*: In test shot 7, the cartridge case was reflected by the steel plate and hit the shooter's hand after a distance of about 25 cm. The primary impact reduced the velocity of the case and the frequency of spins around its transverse axis. The velocity after ricochet was about 2.9 m/s.

   The energy density threshold to induce a full thickness disruption of the human skin is roughly between 0.1 and 0.21 J/mm^2 [19, 20]. The value estimated in our case was more than 20 times lower. Therefore, the impact was not strong enough to penetrate and sever the skin. Tests with free-falling cartridges supported the theoretical energy density threshold. It must however be stressed that the epidermis of the forehead is a stratified squamous epithelium composed of several cell layers and covered with comparatively thin stratum corneum. Even minimal damage to the epidermis can promote a parching process accompanied by brownish discoloration becoming more and more apparent in the post-mortem period. In contrast, the underlying dermis consists of firm connective tissue rich in collagenous, elastic and reticular fibers, which cushions the body from mechanical stress and strain. As the suicide was a 74-year-old man, his skin might have been more vulnerable than the epidermis of the younger test persons due to a reduction of cellular water content. Admittedly, the energy drop of a ricocheting object is influenced by various factors, especially the angle of impact and the nature of the intermediate target [21].

2. *Failure of cartridge case ejection*: An incomplete ejection could be reproduced by incorrectly holding the pistol, when the left hand steadied the weapon. As the right thumb of the suicide was amputated, it seems plausible that he stabilized the pistol with his left hand so that the slide was embraced and the ejection of the cartridge case was impeded. The fact that backspatter was present only on the left hand is compatible with the assumption that the right hand was shadowed by the left. Thus, these findings support the second hypothesis. After losing consciousness, the suicide's head fell down and may have hit a stuck case.

Conclusions

- A parched case mark located in the vicinity of a gunshot entrance wound can be mistaken for being part of a muzzle imprint.
- If the narrow edge of a case mouth impacts the skin, the resulting imprint mark will be ring-shaped.
- In experimental test shots, it could not be proved that the energy density of a ricocheting cartridge case is sufficient to inflict full thickness disruption of the skin.
- A ring-shaped lesion may be caused by the impact of a cartridge case which became stuck in the ejection port.
- A failure of cartridge case ejection might be a hint that the slide's backward movement was impeded.

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