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ORIGINAL ARTICLE

Experimental simulation of reentry shots using a skin-gelatine composite model

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Abstract A bullet that has passed in and out of one body segment may continue its way into another part of the body causing a second entrance ("reentry") wound, which is often said to have an atypical and sometimes confusing appearance. To analyze this problem in a systematical approach, 9-mm Parabellum full metal-jacketed projectiles were fired at skin-gelatine composite models simulating the consecutive passage of a bullet through two parts of a body. When there was a distance between the two segments, the primary exit and the reentry skin wounds did not show any distinctive features differing from usual gunshot injuries. In the case of contact between exit and reentry site, the corresponding skin wounds resembled each other as both had central tissue defects surrounded by abrasion areas. The subsequent investigation of the simulant revealed that skin particles from both the exit and the adjacent reentry site had been displaced in the direction of the shot along the whole bullet track of the second segment. The morphological findings are presented and discussed with respect to the pertinent literature, and possible physical ballistic explanations are suggested.

Keywords Gunshot injury · Reentry wound · Exit wound · Composite model

Dedicated to Prof. Dr. Drs. h. c. Bernd Brinkmann on the occasion of his 70th birthday.

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Introduction

To determine the direction of fire, it is imperative that entrance and exit wounds are interpreted correctly. The morphological diagnosis of a bullet entrance in skin is typically based on the following characteristics: punched-out hole (central tissue defect), abrasion ring (circular loss of epidermis on the wound margin), grayish-black ring of dirt (provided that the projectile did not pass through another target first), and in cases of contact or close-range shots, the presence of the respective signs (e.g., muzzle imprint, soot deposition, or stippling) [1–3, 8, 10, 13, 16–18].

On the other hand, a classical exit wound presents as a slit-like or stellate skin lesion without a real defect so that it can usually be closed by bringing the edges into apposition. Often, although not always, the exit is larger than the bullet entry wound. Exits do not have a bullet wipe and mostly lack an abrasion ring (apart from supported exits).

On the basis of the criteria mentioned above, the investigator is usually able to differentiate entrance and exit gunshot wounds. Difficulties may arise if the morphological features of one or both skin lesions are atypical. From the large number of possible reasons, only a few can be indicated as examples here:

- Bullet entrance wounds with a disproportionately small or completely missing tissue defect (as seen in the palmar and plantar regions [2, 3, 11, 18])
- Absence of the bullet wipe-off in gunshot entrance wounds, if the area of impact has not been the primary target

- Presence of radial splits/tears in non-contact entrance wounds, e.g., from high velocity bullets [2, 3] or in angled shots to anatomical regions with little subcutaneous tissue over the underlying bone (scalp, orbital ridges, or bridge of the nose) [2, 3, 18]
- Entrance wounds with bizarre shapes caused by (deformed and tumbling) ricochet bullets [2, 18]
- Absence of a typical abrasion ring at the entrance site [11, 17] and/or marginal loss of epidermis in supported exits [2, 15–18]
- Disproportionally small exit wounds [2, 6]
- Secondary alterations due to medical treatment [3] or postmortem changes [12, 15]
- Atypical appearance of neighboring exit and reentry wounds, if a bullet passes through more than one part of the body

The latter constellation has been repeatedly addressed as a possible cause of confusing findings which make it difficult to distinguish exit and reentry wounds [2, 3]. Although the problem is well known in the medicolegal literature, to the best of our knowledge, no systematic experiments on this topic have been performed.

Materials and methods

Experimental set-up

Real conditions were simulated by means of test shots to composite models of pigskin (maximum storage time 3 days) and gelatine (prepared in accordance with the recommendation for ballistic gelatine in a 10% concentration [7]). The principal technical procedure has already been described in previous papers [4, 7, 20, 21]. In order to imitate a reentry shot constellation, two cylindrical gelatine blocks (24×8 cm in size) were tightly wrapped in pieces of skin from the belly region of slaughtered pigs and arranged one behind the other by means of a metal rack which permitted the distance between the cylindrical segments to be varied (Fig. 1). The experiments comprised two main series of test shots:

1. The composite models were fixed in a parallel position so that the minimum distance between the segments was 5 cm (Fig. 1a).
2. The two composite models were placed in juxtaposition with each other such that they were in touch at the level of the longitudinal axes (Fig. 1b).

Weapon and ammunition, video documentation

In each of the two main series, ten shots were fired from a pistol (Heckler & Koch USP Compact pistol), caliber 9×19 mm, from a distance of 2.5 m using a 9-mm Parabellum full metal-jacketed projectile manufactured by Dynamit Nobel, Troisdorf, Germany. The bullet mass was 8 g, and the average muzzle velocity was 350 m/s.

One test shot of series 1 was video-documented by means of a high-speed motion camera (Fastcam APX-RS, Photron, San Diego, CA, USA) with 15,000 fps from a 90° side view (Fig. 2).

Investigation of skin particle displacement

In addition to the above-mentioned main series, shots were also fired into composite models after having dyed either the skin of the primary exit site or the skin of the reentry site. For this purpose, the respective areas of the pigskin were submerged in a hemalum bath for 60 min and subsequently dried before they were used to wrap the corresponding gelatine cylinder.

To visualize backspatter from the reentry site in series 1 (distance between the segments), sheets of filter paper moistened with distilled water were mounted in front of the reentry region at a distance of 1 cm. After firing the shot, the filter paper was examined under a stereomicroscope on the side facing the dyed pigskin of the reentry region (cf. [7]).

Analogously, it was also investigated whether skin particles from the dyed exit site were transferred to the filter paper placed between the segments.

In both experimental set-ups (series 1: no contact, series 2: contact between the segments), the gelatine cylinders were laminated in 1-cm thick layers at a right angle to the bullet track. Subsequently, each layer was examined for its content of blue-colored pigskin particles (for details, see [7]). Larger deposits were also examined histologically.

Morphological appearance of the bullet perforation sites

The entrance and exit lesions of the initial segment as well as the reentry and final exit on the secondary target were evaluated as to the presence and measured as to the extent of any central tissue defect and marginal abrasion. For better recognition of the area, in which the epidermis had been lost, the bullet perforation sites were inspected a second time when parching had taken place after prolonged exposure to air accompanied by drying of the unprotected corium.

Results

Series 1

The test shots of series 1 (distance between the segments) were documented using a high-speed motion camera.

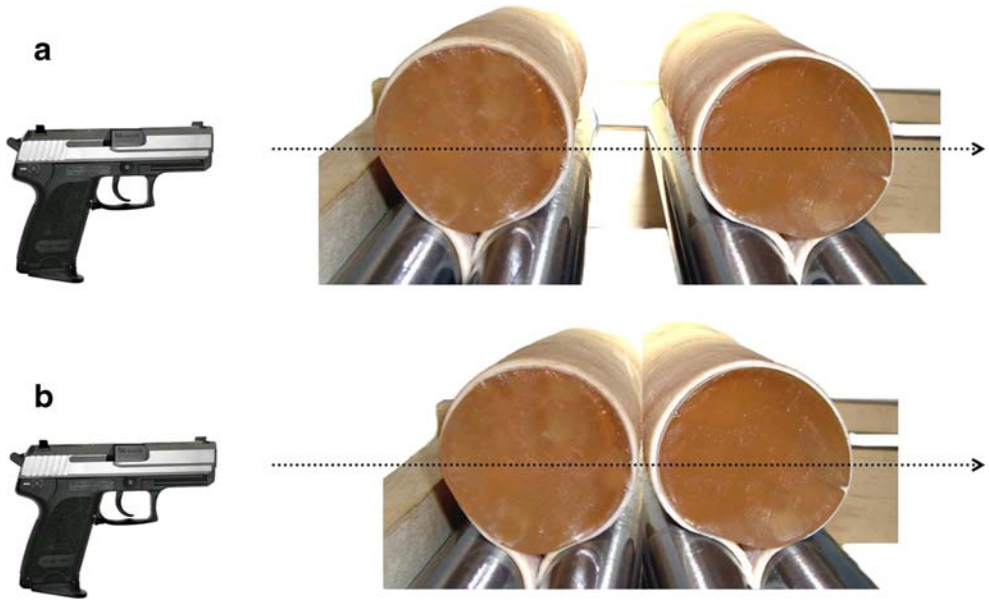

Fig. 1 Simulation of reentry shots by means of composite models consisting of pigskin and cylindrical gelatine blocks. **a** No contact between the segments (series 1). **b** Contact between the segments (series 2)

Figure 2 shows four selected pictures: bullet penetrating into segment 1 (a), bullet just before emerging at the protruding exit site of segment 1 (b), bullet reentering into segment 2 (c), and final exit of the bullet after having passed through segment 2 (d). In both segments, the temporary cavity greatly exceeded the diameter of the projectile. When the still undeformed round-nose bullet left segment 2, the temporary cavity extended from the primary entrance to the final exit. The skin was not indented at the primary and secondary entry sites (a, c), whereas the skin of both exit areas burst outward in the direction of the shot (b, d).

Backspatter of tissue particles up to 1 mm in size was demonstrated on the filter papers mounted in front of the reentry region (Fig. 3a). In accordance with our previous studies [7], stereomicroscopical and histological examination revealed skin particles composed of both epidermis and corium. The other side of the filter paper, which was facing the primary exit area, only showed a very small amount of tiny particles (Fig. 3b), most of which were not visible to the naked eye and consisted of horny scales without structures of the corium.

In the bullet path of the primary target (first segment), a small number of colored particles from the exit site could be detected either within the permanent track or at the end of radial gelatine slits [20]. For the second segment, each section of the bullet track contained skin fragments which had been displaced from the reentry site in an anterograde manner [7].

The primary entrances in the first segments and the reentries in the secondary targets were quite similar in size and appearance apart from the bullet wipe which, as expected, was absent at the reentry sites (Fig. 4a, c). The permanent skin defects in the corium had diameters of only 3–4 mm (due to the high elasticity of pigskin) and were surrounded by typical abrasion rings with a width of about 2 mm.

The first and the final exits (Fig. 4b, d) were both in line with the usual features of bullet exit wounds from pistol ammunition with full-jacketed projectiles. The skin tears could be brought into apposition without any substantial loss of tissue; circular abrasion rings or abraded skin areas as seen in supported exits could not be detected.

Series 2

Both segments of the composite model were in contact when firing the test shots. By dying either the primary exit or the reentry region, the occurrence of skin particle displacement from the bullet perforation sites could be checked. Skin fragments from the primary exit (including corium structures) could be found in every section of segment 2 proving an anterograde displacement along the secondary bullet track (Fig. 5). The same was true for the skin of the reentry site. Skin fragments from the exit and from the reentry were observed also in the bullet path of segment 1, but the number of the retrogradely displaced particles was smaller than in segment 2.

The morphology of exit and reentry lesions (Fig. 6a, b) was characterized by the presence of central tissue defects (diameter 2–3 mm) accompanied by short radial tears (length up to 3 mm). The skin areas surrounding the bullet holes showed irregularly defined abrasions with diameters up to 2 cm. Often, the loss of epidermis was incomplete (restricted to the corneal layer) so that the real extent of the abrasion could only be determined after prolonged exposure to air inducing a brownish discoloration due to drying.

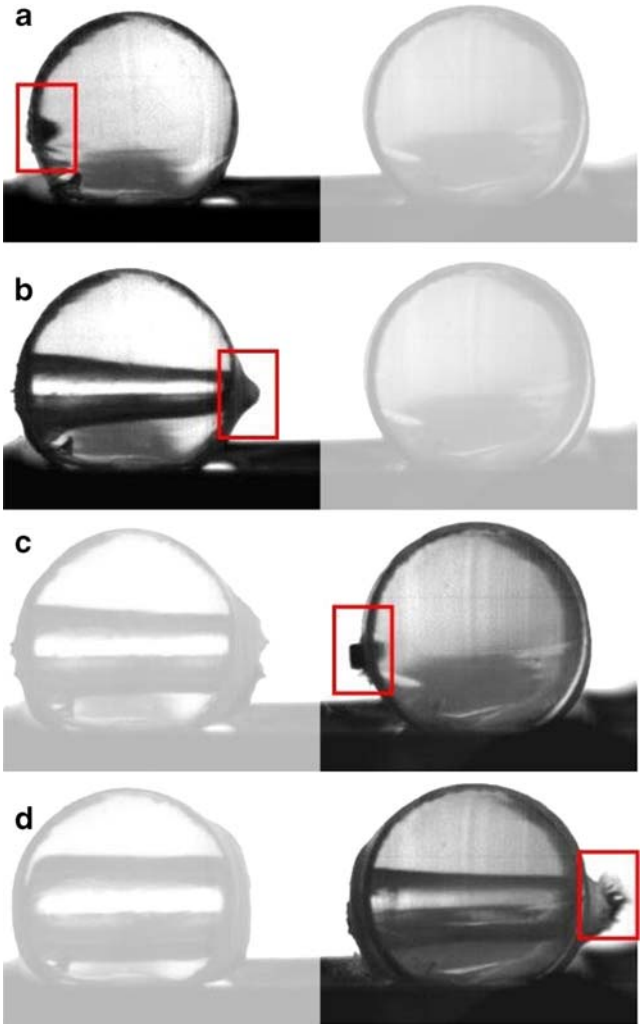

Fig. 2 Test shot of series 1 (no contact between the segments). Sequence of a high-speed video documentation (6,000 fps). For details, see text

Discussion

Reentry gunshot injuries occur when a bullet passes through one part of the body then exits and continues into a second or, even occasionally, a third part. There are some body regions which are prone to reentry gunshot wounds: the chest after initial perforation of an (upper) arm or a female breast (Fig. 7, [3, 18]), the abdominal wall, and the thigh adjoining the groin [5] and the scrotum between the inner aspects of the proximal thighs [3]. Apart from these types of reentry wounds resulting from the close proximity of adjacent body segments, another kind is seen in victims of firearm injuries who raise an arm in an (obviously unsuccessful) attempt to shield vital areas of the body. Under such circumstances, the bullet may first pass through the hand or the arm and afterwards into the head or the trunk producing a reentry wound (defense injuries [8, 14, 15]).

In the medicolegal literature, some special although unspecific and variable features of reentry wounds are described [1–3, 8, 10, 17, 18]:

- Large, ragged, unusually shaped entrance holes
- Surrounded by irregular defined and often disproportionately large superficial abrasion areas
- Sometimes depicting the weave pattern of an overlying piece of clothing

Reentry wounds of the axilla and scrotum have a very atypical (oval or slit-like) appearance with a narrow or even absent abrasion ring so that they nearly resemble an exit wound [2, 3]. On the other hand, the exit wound at the end of the bullet's initial body passage may be a "shored" one with irregularly abraded margins, if the skin was pressed against the area of reentry or supported by tight clothing.

Our own study design was intended to simulate the two main categories of reentries:

1. The cases without contact between the initially perforated body part and the bullet's secondary entrance site (e.g., when the victim had raised his or her arm in order to protect the trunk or head but also in trajectories accidentally affecting body parts with a distance between each other)
2. The cases with contact between exit and reentry site

The modifying effects of interposed textiles and/or a destabilizing bullet passage through bone and/or bullet deformation have not been considered in the set-up of our experimental shots; these potential co-factors will be addressed in a separate study.

1. If there is a distance between the exit site of the initial body passage and the reentrance in the subsequently penetrated body part, both the exit and the reentry

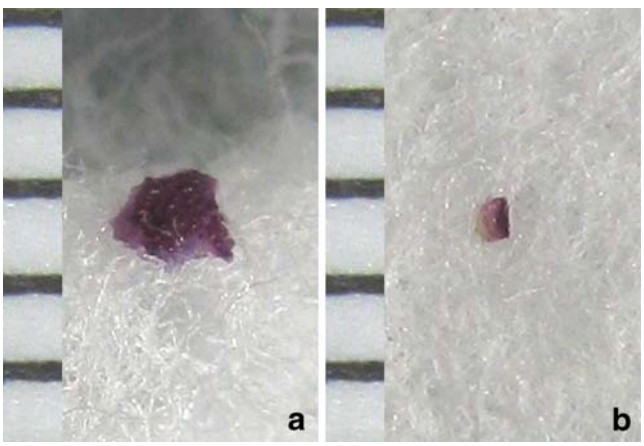

Fig. 3 Test shot of series 1 (no contact between the segments). Stereomicroscopical view of the filter paper which was mounted between the two segments. **a** Adhering backspatter from the blue-colored skin of the reentry region. **b** Anterogradely displaced horny scale from the first exit region

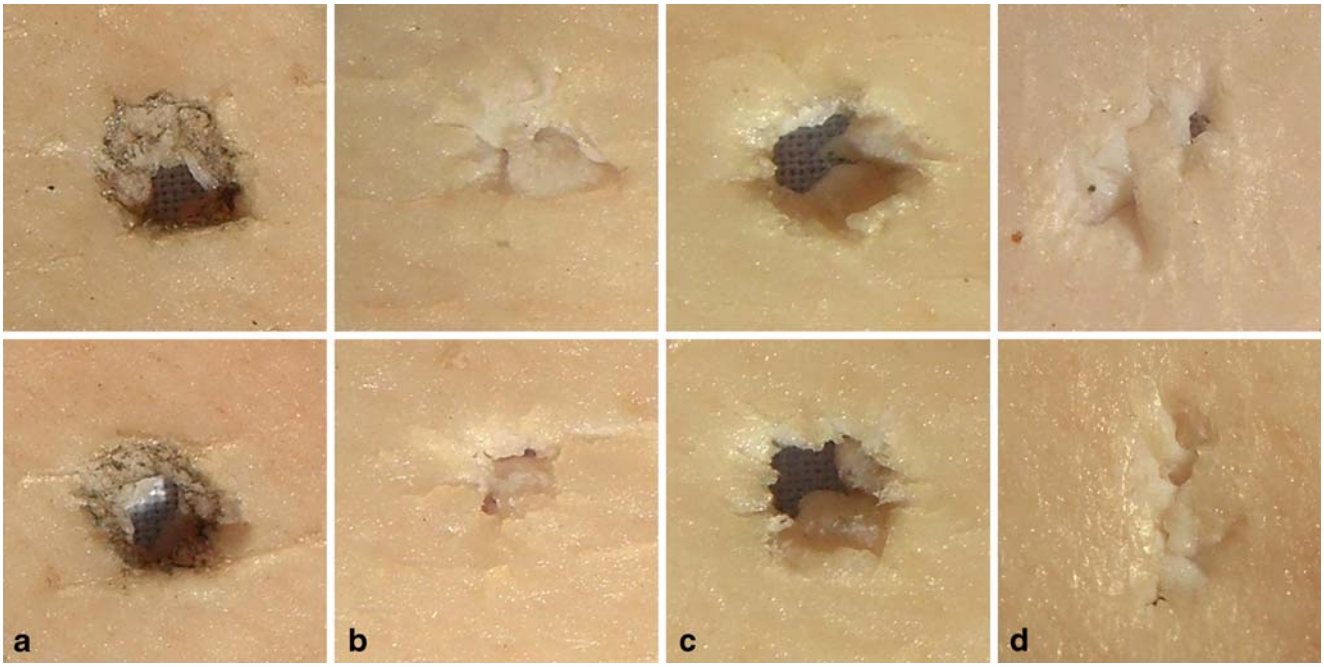

Fig. 4 Two test shots of series 1 (no contact between the segments). **a** Primary entrances. **b** First exits. **c** Reentries. **d** Final exits. For details, see text

wounds are expected to have a typical appearance as described in textbooks. This corresponds with the experience from routine casework and is also confirmed by our test shots to composite models. The bullet exit wounds were slit-like or stellate in shape, the margins could be brought into apposition (no loss of tissue), and they did not show any circular abrasion. Documentation with a high-speed motion camera showed that the exit site bulged outward and overstretched before the skin was finally perforated by the bullet.

The corresponding reentry wounds were characterized by roundish holes with central tissue defects surrounded by typical (narrow and circular) abrasion rings. Pictures taken with the high-speed camera demonstrated that there was no contact between the skin of the exit and reentry area so that an abrading interaction could not take place. At the moment of the bullet's reentry, the usual backspatter of tiny tissue particles ejected backward from the wound edge was observed. In addition, skin particles from the secondary entrance were displaced in an anterograde manner and carried along the whole length of the permanent bullet track (analogous to the findings in bullet paths of primary targets [7]). As expected, the skin level around the reentry site was

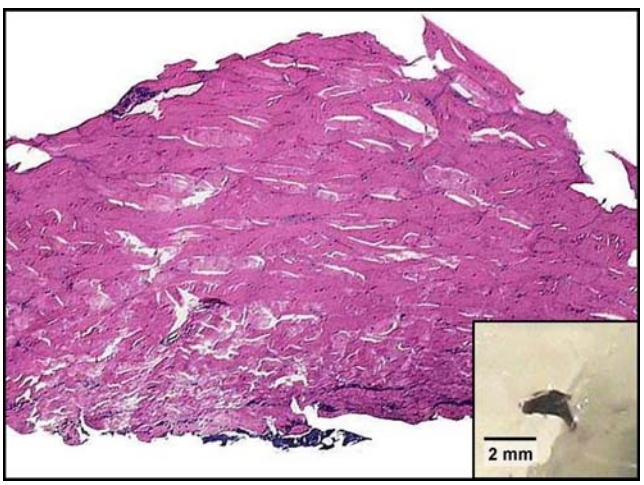

Fig. 5 Test shot of series 2 (contact between the segments). Skin particle displaced from the exit region of segment 1 into the bullet path of segment 2 (histological view, hemalum eosin). The image in the *right lower corner* shows the initial position of the particle in the bullet track

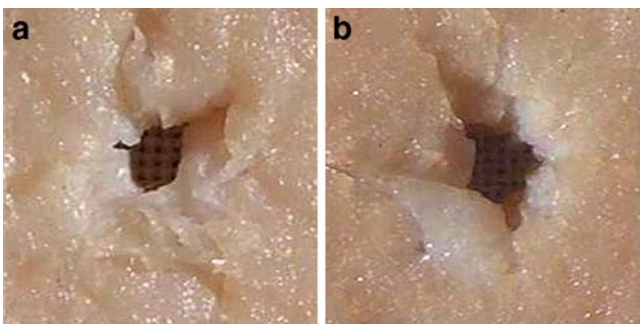

Fig. 6 Test shot of series 2 (contact between the segments). **a** Exit wound of segment 1 with a central tissue defect. **b** Reentry (segment 2) with typical gunshot entrance hole

Fig. 7 Homicide of a 43-year-old woman. Skin wounds from a bullet (cal. 7.65 mm) which passed through three parts of the body. **a** First exit wound at the inside of the left arm. **b** First reentry on the lateral part of the left breast. **c** Second exit at the medial side of the left breast. **d** Second reentry at the medial side of the right breast

neither indented nor bulged out when the bullet penetration took place [19].

2. The test shots of the second series were fired at composite models which simulated two body segments being in contact with each other. Under the chosen conditions, both the primary exit and the reentry wound had an atypical appearance. The exit wounds were quite similar to the adjacent reentry wounds in so far as both had central tissue defects surrounded by large and irregularly defined areas of superficial epidermal loss. Some bullet holes were accompanied by short radial tears. Colored skin particles from the dyed exit site could be demonstrated along the secondary bullet track between the reentry and the final exit wound. Therefore, the tissue which was lost at the primary exit was fragmented and displaced in the direction of the shot. The same anterograde displacement of colored skin particles was found when the reentry site was dyed.

As the skin pieces at the primary exit and the reentry area were in touch with each other, the respective skin surfaces could not be visualized by the high-speed motion camera. Nevertheless, the assumption seems justified that both skin layers behaved in the same way as the adjoining simulant when penetrated by the bullet. As the density of gelatine and human soft tissue is similar, the transfer of energy seems to be comparable in both media.

The exit site of the first segment is supported by the tightly adjoining second segment so that a bullet-induced protrusion with overstretching and consecutive tearing of the skin, as seen in "common" exit wounds, is not possible. Therefore, the physical conditions are analogous to those at the reentry site, which explains the similar appearance. The direct tissue destruction by the bullet results in local crushing, punching, and tearing with the consequence of a permanent skin hole, the size of which inter alia depends on the bullet's shape and velocity, and also on the skin's elasticity.

Another physical effect is caused by changes in pressure and radial displacement of tissue (with stretching and shearing) around the permanent wound channel [9]. The amount of kinetic energy released in the tissue correlates with the diameter of the temporary cavity [3, 6, 8]. The shearing forces affecting the adjacent skin surfaces of the

exit and reentry site give a plausible explanation for the irregular and often disproportionately large abrasion areas around the skin holes.

Conclusions

As a result of our experimental studies on skin-gelatine composite models, the following statements can be made as to the morphological signs of reentry shots:

– If the initially hit body segment and the one hit second are distant from each other at the time of the bullet passage, the primary exit and the corresponding reentry need not differ from the usual appearance of exit and entrance wounds.
– In the case of direct contact between the primary exit and the reentry site, the exit and reentry wounds resemble each other as they are both characterized by central tissue defects surrounded by irregularly defined and often disproportionately large abrasion areas.

Other possible factors which may influence the morphology of exit and reentry wounds remained unconsidered in the present study, for instance, the type of ammunition (especially the shape and design of the projectile), the length of the bullet's passage through the first segment, any bullet deformation or instability after penetration of a dense medium (e.g., bone), and the effect of interposed textile layers (clothing).

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