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ORIGINAL ARTICLE

**Juha Rainio · Kaisa Lalu · Helena Ranta · Antti Penttilä**

# Morphology of experimental assault rifle skin wounds

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**Abstract** Finnish forensic experts who had performed investigations of victims of alleged political violence in Kosovo, in the Federal Republic of Yugoslavia, under the mandate of the European Union, carried out experimental shooting in Finland to confirm observations made during the earlier forensic investigation. Experimental shooting can be of benefit for autopsy conclusions, because the wounding potential of military weapons differs from that of non-military weapons. Assault rifle gunshot wounds were inflicted upon anaesthetised swine from various distances and angles and with variable shielding of the skin. The morphology of the skin wounds was studied and post-mortem changes were documented while the wounds were being observed in cool and room temperature conditions for 13 days. Large variation was found in the size, form, and regularity, and in the presence and width of the abrasion zone of entrance and exit wounds, in addition to secondary wounds. The maximum diameter of entrance wounds varied between 4 and 40 mm and that of exit wounds between 10 and 110 mm. The width of the abrasion zone surrounding entrance wounds ranged from 2 to 11 mm. Extreme care and caution are needed when drawing conclusions with regard to cases of multiple gunshot injuries, and especially when post-mortem changes are considerable.

**Keywords** Gunshot wounds · Assault rifle · Autopsy · Reconstruction · Post-mortem changes

## Introduction

A team of Finnish forensic experts examined victims of alleged political violence in the former Yugoslavia, carrying out investigations under the mandate of the United Nations (UN) in Bosnia and Herzegovina (BiH) in 1996 [1, 2, 3] and under the mandate of the European Union (EU) in Kosovo, in the Federal Republic of Yugoslavia (FRY) in December 1998 and in January 1999 [2, 3, 4, 5].

During the investigations in Kosovo, gunshot injuries were noted which were most likely inflicted by assault rifles. These injuries were visible on the human skeletal remains as well as on the bodies of recently deceased victims [2, 4, 5]. The forensic expert team therefore performed experimental shooting in Finland involving living animals as part of the investigation. Gunshot wounds inflicted by assault rifles are a rare cause of death in Finland [6, 7, 8]; in the former Yugoslavia, as well, assault rifle gunshot injuries had been relatively uncommon in the medical practice before 1991 [9].

Animal models have been widely used for the study of missile trauma [10], with living animals used in experimental studies on wound ballistics to aid in military surgery [11, 12, 13, 14, 15, 16, 17, 18, 19, 20]. Light [21] has studied entrance and exit wounds caused by shooting animals with steel spheres. Experiments have been carried out to determine firing direction from tangential wounds on living animals [22], in addition to examination of shored exit wounds [23]. Histological and ultrastructural changes in gunshot wounds inflicted on living animals have been studied during the several hours after wounding [24, 25, 26]. Experimental arterial injuries have been described [27] and cardiovascular and other pathophysiological effects [28, 29, 30, 31, 32], as well as neuropathological findings from gunshot injuries to living animals [33, 34, 35, 36], and Doppler radar measurements of bullet velocity in ballistic experiments [37]. Furthermore, experimental studies include electrical and thermal injuries to the skin of living pigs and rats in a search for methods applicable to disclosure of electrical torture [38, 39, 40, 41].

Our experiments focused on variation in the morphology of skin wounds inflicted by one weapon and the same type of bullets, and the macroscopic post-mortem changes in the wounds under differing temperature conditions.

J. Rainio (✉) · K. Lalu · H. Ranta · A. Penttilä
Department of Forensic Medicine, P.O. Box 40 (Kytösuontie 11), 00014 University of Helsinki, Finland
e-mail: juha.rainio@helsinki.fi, Fax: +358-919127518

## Materials and methods

Domestic white swine ($n$=4), each 70–80 kg in weight, were anaesthetised by a veterinary surgeon who was present during the whole experiment. For premedication, 280 mg azaperone was given intramuscularly. After 20 min the swine received intramuscular injections of tiletamine (250 mg), zolazepame (250 mg), and medetomidine (2 mg). They were left on spontaneous air breathing but within 5 min the animals were in a deep sleep and this narcosis lasted until death.

The animals were shot while in deep narcosis but the exact moment of death, i.e., that of cardiac arrest, went unrecorded. At the time of the experiment, in early spring 1999, Yugoslavian ammunition was unavailable in Finland, so all shooting experiments with the AK-47 assault rifle, were carried out with the Lapua 7.62×39 cartridge. According to the manufacturer, this bullet has a velocity of 705–661 m/s at distances of 5–50 m. The experiments took place outdoors on 10 March 1999 when the air temperature was approximately –6°C.

The swine were coded as 100, 200, 300, and 400. The animals were first lying on their stomachs or on their sides, fixed on a wooden bench, and later, on the ground (Fig. 1). Every entrance gunshot wound was immediately marked with waterproof ink. Entrance wounds were coded with even numbers. Exit wounds were marked afterwards and coded with odd numbers. After every shot, each entrance wound was photographed and videofilmed.

The shooting was performed perpendicular to the vertebral axis from distances of 10, 25, and 45 m and 10, 20, 30, 50, 70, and 100 cm into the lumbar and abdominal areas and into the back, chest, head, thigh, and elbow. Contact shots were directed into the head, elbow, chest, and thigh. Seven hits were inflicted on the chest from a distance of 2 m at an angle of 15–40°. In total, seven tangential hits were directed into the back area from a distance of 10 m for a living (code 300) swine as well as a dead one (code 200). Three shots were inflicted from 7 m on the chest area of a swine through the torso of another swine. All these hits struck uncovered skin. Furthermore, four hits struck skin covered with three layers of clothing. Two of these were contact shots to the chest and to the elbow; the other two were shots into the neck from 10 cm and from 10 m. Of the total of 53 entrance wounds, 47 were perforating, and 6 bullets remained within the animals. The general conditions of the experiment are presented in Table 1.

After the shooting, the animals were transported to the Department of Forensic Medicine, University of Helsinki where two of them (200 and 400) were placed in an autopsy room (+23°C) and the other two (100 and 300) in a cold room (+4°C). The animals lay with entrance wounds upwards.

After the first inspection and documentation of the wounds in the Department of Forensic Medicine, the hairs around the wounds were shaven and removed with a standard vacuum cleaner. A lateral x-ray was taken of each swine including the head, as well as the thoracic and abdominal and the thigh areas in order to document any bullets and bullet fragments retained inside the animals.

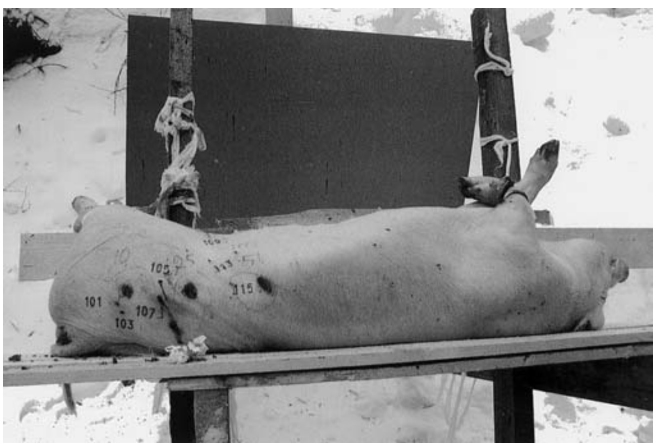


**Fig. 1** Position of swine on the bench

**Table 1** General description of the experiment

| Experimental details | Swine number | | | |
|---|---|---|---|---|
| | 100 | 200 | 300 | 400 |
| Number of entrance wounds | 12 | 14 | 19 | 8 |
| Exit wounds | 12 | 9 | 19 | 7 |
| Tangential wounds | – | 3 | 4 | – |
| Contact wounds | 2 | 1 | 2 | 1 |
| Post-mortem temperature (°C) | +4 | +23 | +4 | +23 |
| Autopsy day (post-mortem) | 13 | 9 | 13 | 9 |

The form and maximum diameter of every wound, the existence and maximum diameter of abrasion around the wound and rupture were recorded in a protocol as well as other features when noted. Every entrance and exit wound on the two swine kept in the cold room was photographed and videofilmed separately on days 1, 2, 3, 5, 7, 9, and 13. On the final day, an autopsy was carried out. The wounds on the other two swine, kept at room temperature, were documented on days 1, 2, 3, 5, 7, and 9, and the animals were autopsied on that final day.

Skin samples for histological examination were taken from the margins of the entrance wounds for detection of foreign material. Additionally, skin samples were taken from the margins of four tangential and six exit wounds. These samples were prepared with standard haematoxylin-eosin and with Weigert-van-Gieson staining methods for light microscope examination.

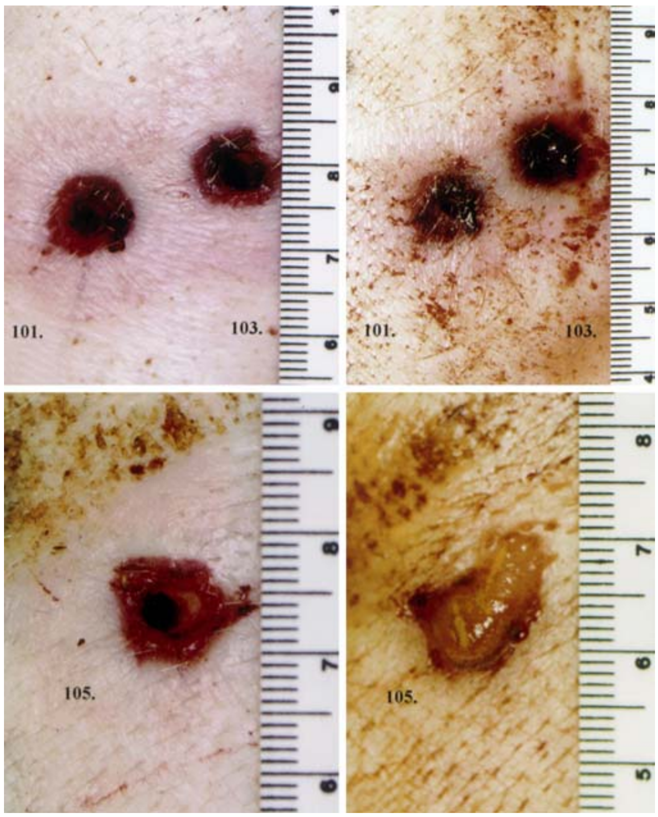



**Fig. 2** Close-up photographs of a pair and of a single entrance wound on days 1 *(left figures)* and 13 *(right figures)* post-mortem. This swine was kept post-mortem at +4°C

**Table 2** Main findings for wound appearance

| Criteria measured | Entrance wounds | | | Exit wounds | Secondary wounds (total 2) |
|---|---|---|---|---|---|
| | Shooting distance ≥7 m | Shooting distance 10–100 cm | Contact | | |
| Average maximum diameter of wounds (mm) | 5 | 9 | 21 | 39 | 4.5 |
| Maximum diameter (mm) | 4–25 | 3–22 | 5–40 | 10–110 | 2–7 |
| Margins ruptured (%) | 18 | 9 | 17 | 27 | 0 |
| Abrasion zone present (%) | 100 | 100 | 5 | 62 | 50 |
| Average maximum width of abrasion (mm) | 4 | 3 | 3 | 9 | 3 |
| Maximum width (mm) | 2–11 | 2–4 | 2–5 | 3–35 | 3 |

## Results

The form of the entrance wounds inflicted perpendicularly on the skin surface from a distance of 7 m or more was regular. The maximum diameter was approximately 5 mm, and each wound was surrounded with an abrasion zone measuring 3–4 mm on average (Fig. 2). Entrance wounds inflicted from a distance of 10–100 cm had a regular, mostly round form, the maximum diameter was 9 mm on average and the surrounding abrasion 2–4 mm. As the angle of the bullet entrance lessened, the injury extended to 22 mm in diameter, the abrasion ring extended to 11 mm, and the form of the injury became oval or irregular. The actual entry hole, however, remained relatively round and extended in some cases to 8–9 mm (Table 2).

The six contact wounds were of a regular round or oval form, except one in the thigh area, with an irregular form and ruptured margins. The average maximum diameter was 22 mm, but one contact wound to the head was 6 mm in diameter, leaving the average diameter of the rest of the wounds as 25 mm. The contact wounds were surrounded with an abrasion zone 2–5 mm in width. The two contact wounds inflicted through clothing, or the abrasion surrounding them did not differ from the other contact wounds.

The exit wounds to the head had a maximum diameter of 28 mm on average, to the back 36 mm, to the abdominal and thoracic areas 37 mm, to the neck 18 mm, to the thigh 39 mm, and to the elbow 38 mm. The form of 25 exit wounds (53%) was irregular, 14 (30%) round or oval, and 8 (17%) had a linear form. An abrasion 9 mm on average in width was recorded in 62% (Fig. 3).

The margins of 6 entrance wounds (11%) were ruptured and of these three were inflicted on the back area from 10 m, 2 on the neck through clothing from 10 m and 10 cm. One of the wounds was from a contact discharge inflicted on the thigh. In the exit wounds rupture of the margins was noted in 13 cases (28%) and of these 3 were on the chest, 2 on the head, 2 on the elbow, 2 on the neck, 2 on the thigh, 1 on the back, and 1 in the abdominal area. See Table 2.

The average length of the tangential wounds located on the back area was 55 mm. They had a linear or, in one case an oval form. Inside the wounds subcutaneous tissue was visible and the margins were surrounded by a darkish,

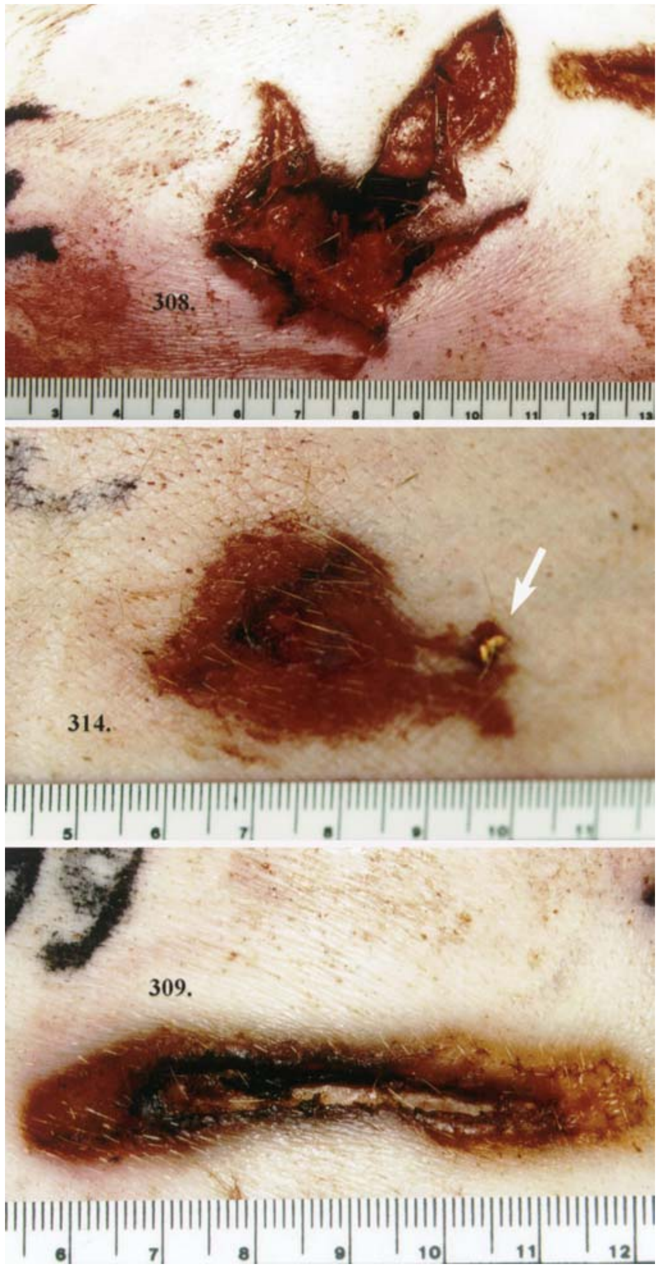



**Fig. 3** Close-up photographs of two exit wounds (308 and 314) and one tangential gunshot wound (309). Exit wounds are surrounded by an abrasion-like zone. In one of the exit wounds a bullet fragment is visible *(arrow)*

**Fig. 4** Differences in appearance of, and post-mortem changes in tangential wounds inflicted on a dead and a living animal. The wounds (227, 229, 231) in the dead swine are in the upper photographs and the wounds (309, 311, 313 and 317) in the live swine in the lower. The left-hand pictures were taken immediately after the shooting at the shooting site. The right-hand ones were taken in the autopsy room on day 2 *(right upper figure)* and on day 12 *(right lower figure)* post-mortem. The animal in the upper photographs was kept at +23°C post-mortem, and the one in the lower at +4°C

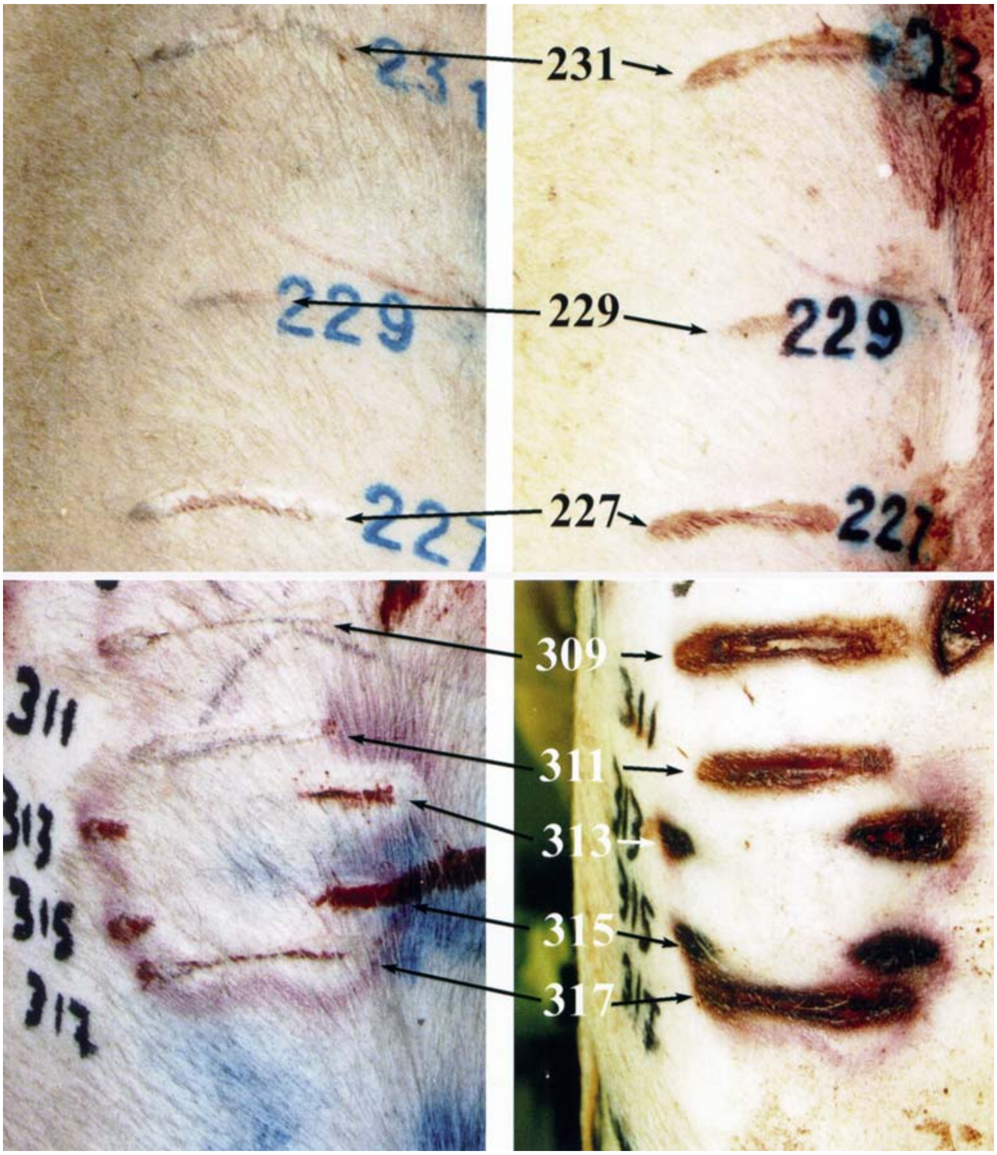


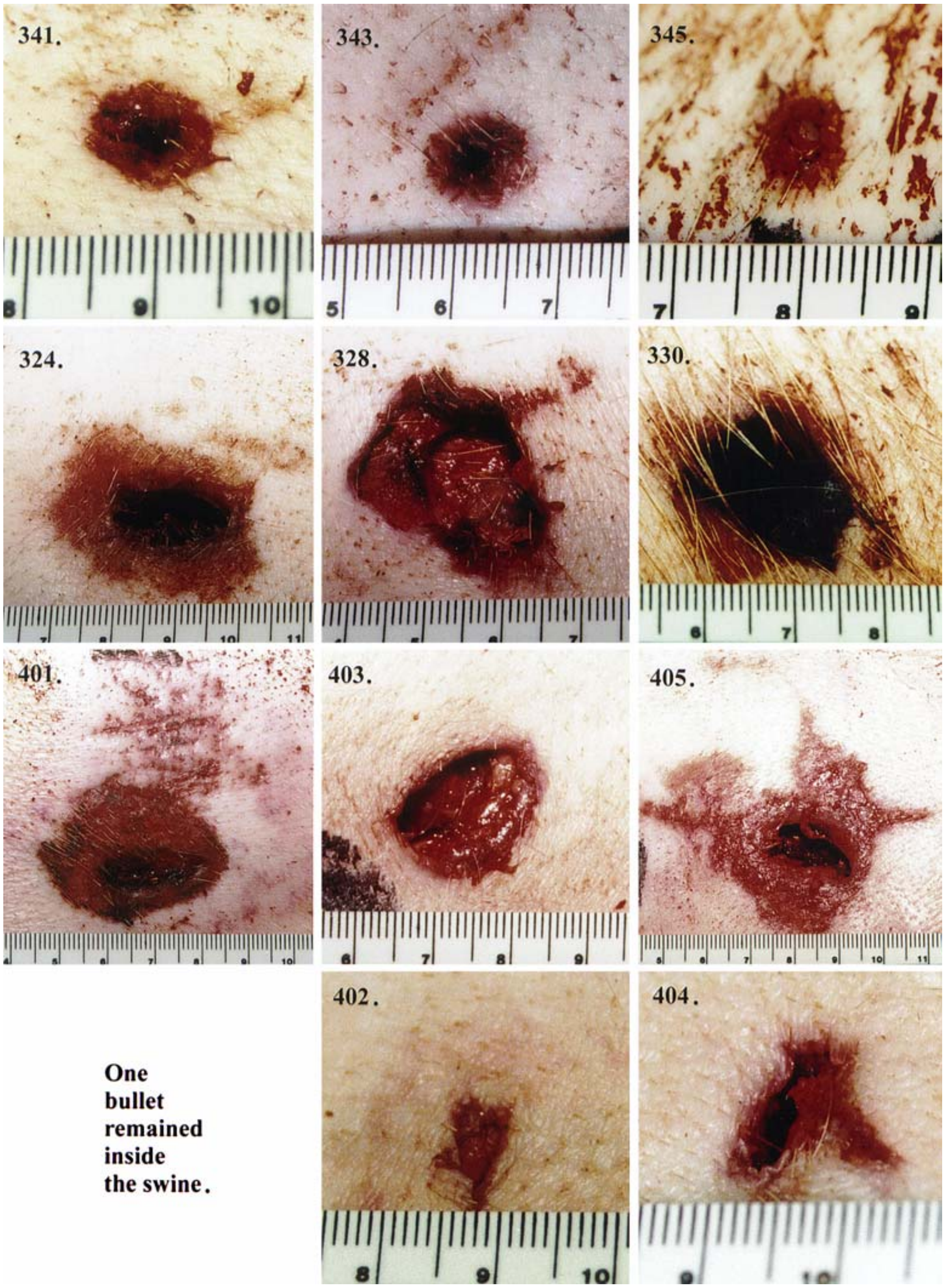

**Fig. 5** Position of the two swine when three gunshot hits were inflicted through them both sequentially

**Table 3** Characteristics of gunshot wounds inflicted through two swine

| Wound and location | Maximum diameter (mm) | Round or regular form (%) | Maximum width of abrasion zone (mm) |
|---|---|---|---|
| Entrance wounds | | | |
| First swine | 9 | 100 | 4 |
| Second swine | 25 | 100 | 14 |
| Exit wounds | | | |
| First swine | 23 | 67 | 10 |
| Second swine | 14 | 0 | 0 |

dry abrasion-like zone (Fig. 3). The four tangential wounds inflicted on the living animal were surrounded by an inconstant vascular reaction of a fluctuating hyperaemia antemortem. The post-mortem difference between these tangential wounds inflicted on the living animal and the wounds on a dead animal was obvious (Fig. 4).

**Fig. 6** Photographs showing entrance and exit wounds inflicted by the three hits shot through two swine. In line one at the top are entrance wounds and in line two exit wounds in the first animal. The third line shows entrance wounds on the latter swine and the lowest line the two exit wounds




Two secondary wounds were caused either by fragments of the bullet or pieces of broken bone. One was situated in the elbow and one in the abdominal area. The first was linear in form, maximum 2 mm in diameter and the latter had a round form and a diameter of 7 mm (see Table 2).

Black granular material was visible in the microscopic examination of 3 samples of the 12 wounds at a shooting distance of 2 m, in 1 sample from the 3 wounds inflicted from 7 m, and in 1 sample from the margins of 10 wounds at a shooting distance of 10 m. Similar material was seen in all samples from wounds at a distance of less than 2 m.

No unusual macroscopical or microscopical characteristics appeared in the four injuries inflicted through clothing. The histological samples from these wounds showed black granular material. No fibres from clothing or any other specific foreign material were evident.

Three hits were inflicted on the trunk area of two swine lying on their stomachs on the ground side by side but without bodily contact (Fig. 5): see Table 3 and Fig. 6. The entrance injuries to the first swine had diameters of 7, 9, and 9 mm with a narrow abrasion zone and a round form. The exit wounds had a maximum diameter of 18, 23, and 23 mm, respectively. Two of the wounds had a regular form, and one

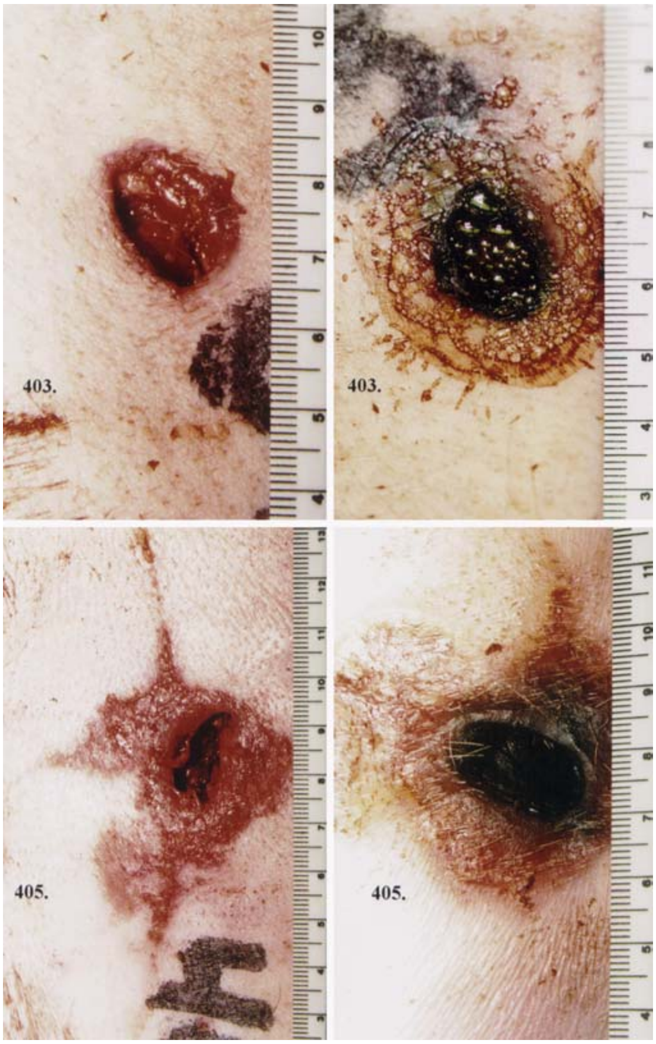



**Fig. 7** Close-up photographs on the second post-mortem day of two entrance wounds (403 and 405), caused after the bullet had already penetrated another swine. On the right are these wounds on days 4 (403) and 7 (405) post-mortem. Post-mortem temperature for the swine was +23°C

was irregular: all were surrounded by an abrasion zone with a maximum width of 10 mm. The entrance wounds to the second swine were 25 mm, 25 mm, and 18 mm maximum in diameter, regular, oval or round in form and were surrounded by an abrasion zone witha maximum width of 14 mm. One of the bullets remained in the vertebral column of the second animal, but two bullets made an exit wound which had an irregular form and a maximum diameter of 11 mm and 14 mm. Microscopically, also in the margins of one entrance wound in the latter swine undetermined black granular foreign material was seen.

The x-rays of the swine showed x-ray-positive foreign material, including fragments of bullets. During the autopsy, devastating injuries to the organs and skeletal structures were evident. However, there was no correlation between internal injuries and the diameter of exit skin wounds.

As a result of post-mortem changes, the abrasion surrounding each wound became darker in colour and clearer in contrast to the surrounding skin. The injury became more dry and the actual entry hole more difficult to establish in the injury. As the general post-mortem changes in the swine kept at room temperature were more prominent, changes noted in the wounds were also more significant. In the decayed wounds, the form and diameter of the actual hole in the injury became more difficult to estimate. Nevertheless, the form of the wounds and abrasions as well as the diameter of the wounds remained quite similar to those seen on the first day (Figs. 2, 4, and 7).

## Discussion

The fundamental question from the medical and legal points of view in investigation of victims of violent death, is the definition of the cause and manner of death. Furthermore, autopsy conclusions may help in reconstruction of events. In this respect, the morphology of gunshot skin lesions can be considered valuable, especially in the case of multiple gunshot injuries [42]. For these conclusions, it is necessary to define the total number of wounds, to differentiate the entrance and exit wounds, and to estimate the vitality of the wounds. Partly on the basis of wound morphology, the combination of the exact entrance and exit wounds of each bullet hit becomes possible, which helps to determine bullet path directions inside the body. Hereby, internal injuries become more understandable, and it also becomes more apparent to draw conclusions as to the direction of fire in relation to the body [43, 44, 45, 46]. In addition, sustained firing for example may become evident [4]. In estimation of shooting direction and discharge range, mere skin wound morphology can also have some significance, because wounds from contact, close-range and long-distance shotshave their own characteristics [21, 22, 44, 46, 47, 48, 49, 50, 51, 52]. Wound morphology can provide useful information for the identification of the weapon, as well. However, gunshot wound appearances can vary quite considerably, not to mention that post-mortem changes may seriously complicate the investigation [45].

The appearance of gunshot entry wounds is basically determined by the weapon calibre, the structure, mass, velocity and stability of the projectile, and the distance and angle of the discharge of fallen projectiles, in addition to the anatomical site of entrance [11, 14, 16, 17, 20, 21, 43, 44, 47, 51, 52, 53, 54, 55].

Destruction of the tissues is related, for one thing, to the amount of transferred kinetic energy from projectiles [11, 12, 14, 16, 43, 56]. This amount depends on the velocity and mass of the bullet and on resistance of the tissues. Secondly, destruction is related to the type and stretching properties of the tissue [11, 17, 47, 54, 55, 56, 57]. Furthermore, tissue destruction as well as bullet deformation and fragmentation have secondary effects on exit wound appearance [14, 15, 17, 45, 55]. Therefore, variation of the wounds can be extensive (see Table 2). In our study, the maximum diameter of exit wounds ranged from 10 mm to 110 mm. Furthermore, the size of the skin wounds and the internal injuries did not always correlate [11, 20, 58]. The variation of the skin wounds inflicted with the same weapon and same projectiles in our experiment showed that it is quite difficult to draw conclusions concerning the use of different weapons and bullets based only on the different gunshot wounds.

Nevertheless, experimental shooting can be convenient for clarification of the injury mechanism when there is an initial identification of the ammunition obtained by autopsy examination. There are, however, several reservations, because the reproducibility of ballistic experiments using live animals is extremely difficult [15].

In some respects, reconstruction of events can be complicated by the capability of military bullets to pass through more than one individual, as was demonstrated also in our experiment [46]. In addition, uncertainty can be produced by the observation that contact wounds inflicted through clothing were rather difficult to distinguish from non-contact lesions both macroscopically and microscopically, as also reported previously [43, 49].

Furthermore, sometimes the margins of the exit wounds can show changes relatively similar to those of the entrance wounds [21, 59]. An abrasion-like zone around the exit wound is usually related to a so-called shored or supported exit wounds [23, 47, 53, 59]. In our experiment, however, abrasion-like changes were seen in some exit wounds without shoring material (see Table 2). This phenomenon was probably in part based on the properties of swine skin. To ascertain and interpret this, as well as the effect of kinetic energy in this respect requires further examination. Our small material size does not allow specific conclusions.

Another phenomenon seen in our experiment was the lack of secondary wounds (see Table 2), whereas in autopsy material secondary wounds are commonly noted [4]. This difference can probably be explained on the basis of the quality of the animal tissues; porcine tissue will more often tear into a larger wound rather than form secondary wounds near the exit.

Wounds in swine are not directly comparable to those in human beings because of the differences in the thickness and structure of the skin and subcutaneous tissue and, especially, in the retracting properties of human and porcine skin. The average tensile strength of porcine and adult human skin may differ. When the percentage stretch of the skin in vivo of several animals and humans was determined, the skin of adult swine proved to have less elasticity (22.2%) than human (37.2%), dog (37.1%), or rat (57.1%) skin [60]. Furthermore, as the gross anatomy of the swine differs from the human, the bullet paths and, consequently, the exit wounds may take different forms [10, 14, 61].

Post-mortem changes can seriously complicate the medicolegal investigation of death. In this experiment, the post-mortem period was 9 and 13 days, and the changes were still relatively incipient. As a result of post-mortem changes, however, it became more difficult to see the difference between entrance and exit wounds. Changes in the skin lesion indicating the bullet direction in relation to the skin became less obvious. On the basis of our experiment, we would consider the documentation of post-mortem changes by exact daily measurements of the wounds to be informative. In addition, learning the effect of more severe post-mortem changes would very likely be valuable.

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