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ORIGINAL ARTICLE

Textile fibres along the bullet path–experimental study on a skin-gelatine composite model

B. Vennemann · F. Dautel · R. Braunwarth · E. Straßburger · M. Hunzinger · S. Pollak · M. Große Perdekamp

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Abstract In the past, the presence of textile fibres in the bullet track of gunshot injuries in body regions covered with clothes was used to differentiate between entrance and exit wounds; as with handguns, a displacement of textile fibres was considered possible only in the direction of the shot. In the present study, the transfer of textile fibres from the entrance and exit regions into the bullet path was systematically investigated with the help of a skin-gelatine composite model. For this purpose, the skin of the bullet entrance and exit region was covered with textile fabric (jeans or jersey material), before conducting four test series of ten test shots each firing a 9-mm Parabellum full-jacketed projectile from a distance of 2 m. The length of the bullet track was 25 and 8 cm, respectively. Subsequently, the bullet tracks were microscopically investigated in sections for the presence of textile fibres. In all the investigated bullet tracks, textile fibres both from the entrance and exit regions could be demonstrated. The distribution pattern depended on the length of the bullet path and the extension of the temporary cavitation. The results are discussed in relation to the relevant literature.

Keywords Gunshot wound · Bullet track · Textile fibres · Composite model

B. Vennemann (✉) · F. Dautel · S. Pollak · M. Große Perdekamp
Institute of Legal Medicine, University Hospital Freiburg,
Albertstraße 9,
79104 Freiburg, Germany
e-mail: benedikt.vennemann@uniklinik-freiburg.de

R. Braunwarth
Freiburg Regional Council,
Kriminaltechnische Untersuchungsstelle,
Berliner Allee 3 a,
79114 Freiburg, Germany

E. Straßburger · M. Hunzinger
Fraunhofer Institute for High-Speed Dynamics,
Ernst-Mach-Institut (EMI),
Am Christianswuhr 2,
79400 Kandern, Germany

Introduction

In gunshot injuries, examination of the clothing is often as important as examination of the body [3]. In cases of close and intermediate range shots, the clothing can absorb soot and/or powder grains either completely or in part, so that the appearance of the skin wound simulates a greater distance between muzzle and bullet entrance site. Therefore, in body regions covered with clothes, the range of fire can only be determined by investigating the textiles, especially the outer layer, e.g. by means of SEM-WDX analysis [8]. Even in distant shots, the clothes may help to differentiate between entrance and exit holes, as the bullet entrance is characterised by a narrow "ring of dirt" consisting of soot, which is carried by the projectile and wiped off when passing the clothing. Textile fibres from a perforated garment may be deposited on the epidermis-free abrasion collar and in the depth of the entrance wound where they can be demonstrated microscopically [11, 12].

Even in the middle of the 19th century, it was known that "particles of textiles" can be found in the depth of the bullet track [1]. In the first half of the 20th century, the question was discussed whether the presence of textile fibres in a gunshot wound may be suitable to differentiate between entrance and exit wounds [9, 16]. It was assumed that the number of textile fibres at the bullet entrance site was clearly higher than at the exit site. In his famous monography "On firearms and their injuring effects" [13],

Table 1 Characteristics of the four test series

Test series	Length of gelatine blocks (cm)	Textile fabric	Number of test shots
Series 1	25	Jeans	10
Series 2	25	Jersey	10
Series 3	8	Jeans	10
Series 4	8	Jersey	10

Karl Sellier claimed that a retrograde displacement of textile fibres from the exit site into the wound channel was possible only with high velocity (HV) projectiles due to the subpressure developing in the temporary wound cavity, but not with shots from handguns.

Spitz only discussed the orthograde displacement of textile fibres in the direction of the shot: "... pieces of fabric may be carried into the entrance wound. It is rare that such pieces are carried through the wound und deposited at the exit, except if the shot involves a thin part of the body, such as a hand, or in the case of a grazing shot" [15].

In previous studies, tests with composite models of pig skin and gelatine demonstrated an anterograde transport both of skin particles and microorganisms from the entrance site and a retrograde displacement from the exit site back into the bullet path [5, 19]. Based on these findings, the question arose whether textile fibres from the bullet entrance and exit region are also displaced in a comparable way and whether the presence of textile fibres in the bullet track is really a reliable criterion for the distinction between the entrance and exit wounds. For this purpose, composite models consisting of pig skin and gelatine were covered with textile fabrics (jeans or cotton jersey) on the entrance and exit sides before firing test shots.

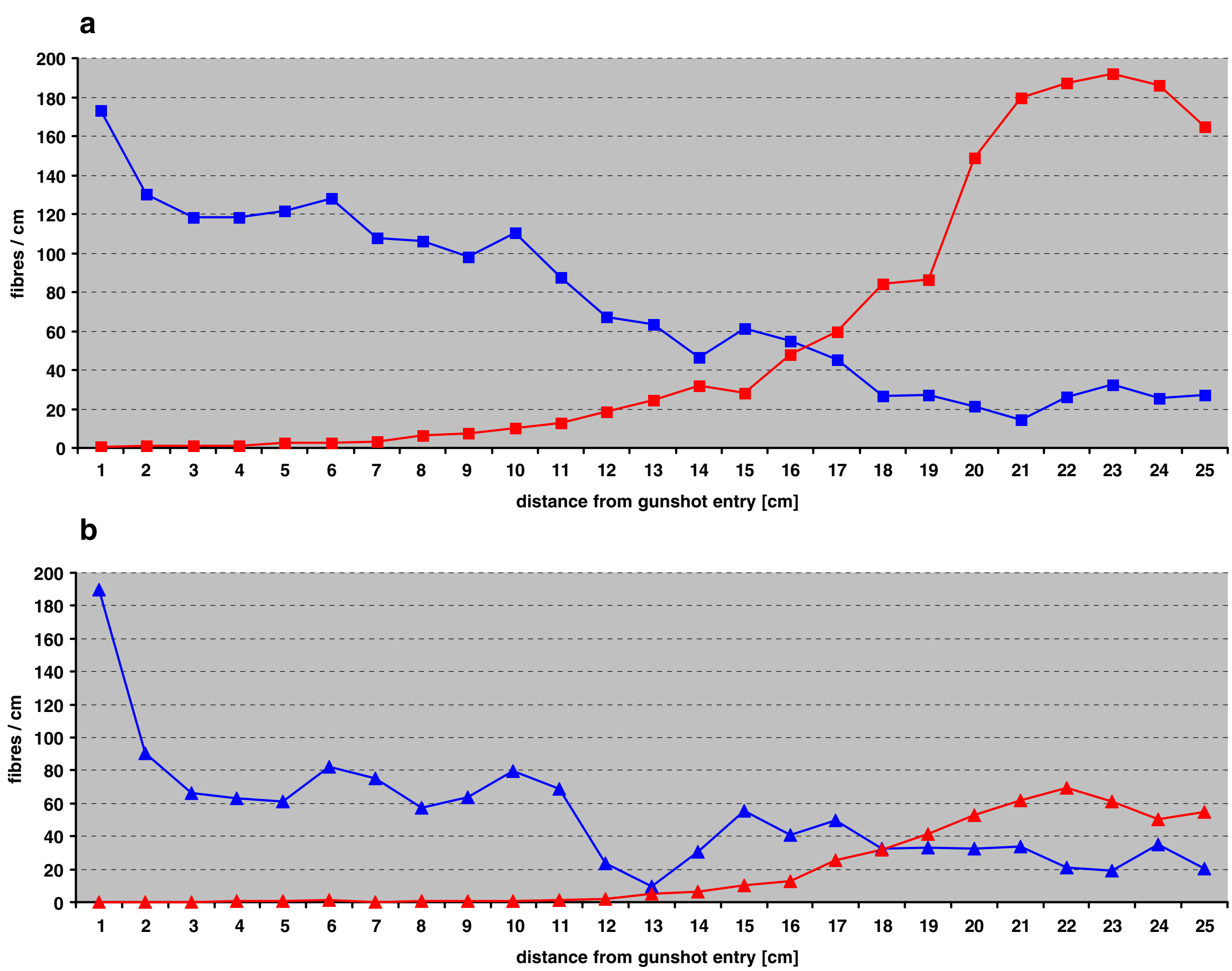


Fig. 1 Diagram of the mean values of fibre density in the bullet track for test shots to 25-cm-long composite models. *Blue curves*: fibres displaced from the bullet entrance site. *Red curves*: fibres displaced from the bullet exit site. **a** Fibre distribution with jeans material. **b** Fibre distribution with jersey material

Materials and methods

Gelatine blocks measuring 25×12×12 cm (length of the bullet path 25 cm) and 8×12×12 cm (length of the bullet path 8 cm) were prepared in accordance with the recommendations for ballistic gelatine in a 10% concentration [4, 7]. Skin pieces from the belly region of freshly slaughtered pigs were fixed to the front ends (12×12 cm in size) of the gelatine blocks with dental instant glue (Renfert, Hilzingen, Germany) in the areas of the later entrance and exit site. Before firing the shots, a layer of textile material was loosely fixed in front of the entrance and behind the exit regions with the help of a rack.

For the test shots, two kinds of textile material were used:

– 100% cotton denim (333 g/m^2, Hilco Textil, Echterdingen, Germany)
– jersey made of supercombed cotton (190 g/m^2, EWI Textil, Winterlingen, Germany).

Both textile fabrics were dyed through. To distinguish the fibres of the entrance site from those of the exit site, the skin of the entrance region was covered with blue, and the skin of the exit region with red fabric.

The shots were fired from a pistol (Heckler & Koch USP Compact Pistol), calibre 9×19 mm, from a distance of 2 m using a 9-mm Parabellum full-jacketed projectile manufactured by Dynamit Nobel, Germany. The bullet mass was 8 g, and the average muzzle velocity was 350 m/s. The experimental set-up of the four test series is indicated in Table 1.

After firing the shots, the gelatine blocks were laminated in 1-cm-thick layers under sterile conditions, and the area of the bullet track was cut out of each gelatine slice. The excised gelatine pieces had a volume of approximately 500 µl. They were liquefied in Eppendorf reaction vessels at 38°C and centrifuged at 10,000 rpm for 30 min. From the resulting sediment, thin smears were taken for microscopic examination to determine the number of blue and red textile fibres.

The length of the slits radiating from the geometric bullet path was measured in three gelatine blocks of test series 1 and 2 as an indicator of the extension of the temporary cavitation ("crack length procedure" according to Knappworst) [14]. One test shot to a gelatine block of test series 1 (bullet path length 25 cm, jeans material) was video-documented by means of a high-speed motion camera (Photron FastCam APX RS, 6,000 fps) from a 90° side view.

Results

Distribution of textile fibres in the bullet path

Series 1 and 2

In the test shots to 25-cm-long gelatine blocks, blue textile fibres from the entrance region could regularly be demonstrated along the entire bullet path. The highest number of these blue fibres was found near the bullet entrance site and decreased discontinuously towards the end of the bullet track (Fig. 1a,b). The test shots produced comparable results for jeans and jersey material.

Red textile fibres from the exit region could be demonstrated in large numbers both after test shots to jeans and jersey material in the distal third of the bullet track (17–25 cm away from the bullet entrance site; Fig. 1a,b). As the gelatine was transparent, the coloured fibres were visible to the naked eye even by transmitted light (Fig. 2). Occasionally, red textile fibres had been transported backwards along the entire length of the bullet path right to the bullet entrance site (Fig. 1a,b). The absolute figures of the fibres from the exit site were higher with jeans than with jersey material. The maximum fibre density was seen with jeans material at a distance of 23 cm behind the bullet entrance site (mean value 192 fibres/cm). For jersey, the maximum value was 69 fibres/cm at a distance of 22 cm behind the entrance site.

Figure 3 gives an example of the microscopic evidence of displaced textile fibres from jeans fabric. In the analysed section (15 cm away from the entrance site), the fibres displaced in an anterograde or retrograde direction can be clearly distinguished by their colour.

Series 3 and 4

In the test shots fired at 8-cm-long gelatine blocks, blue textile fibres displaced from the bullet entrance site in the

Fig. 2 Transmitted light print of a 25-cm-long bullet track of series 1. Near the bullet exit, *red textile fibres* transferred in a retrograde direction are macroscopically visible

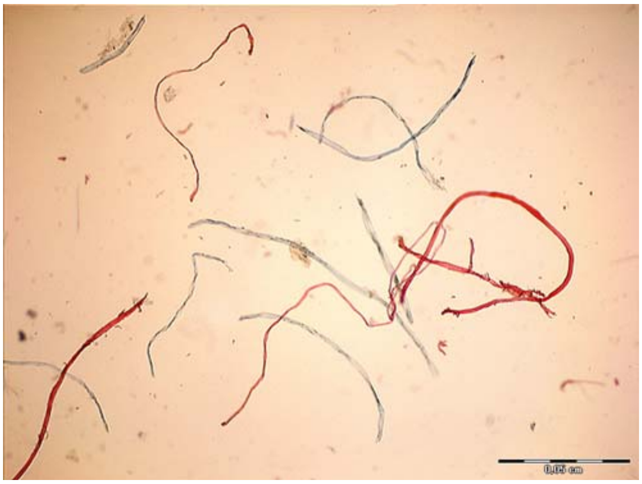


Fig. 3 Microscopic demonstration of displaced jeans fibres from the entrance region (*blue*) and the exit region (*red*) in a bullet track of series 1 at a distance of 15 cm from the bullet entrance site (×100 magnification)

direction of the shot could be demonstrated along the entire bullet track. The fibre density was 150–200 fibres/cm on average for shots fired at jeans material and 100–200 fibres/cm for shots at jersey material (Fig. 4a,b).

Red jersey fibres displaced in a retrograde direction from the exit site were found in very small numbers discontinuously along the entire length of the bullet path. The average fibre density was < 5 fibres/cm. With jeans material, the density of fibres displaced in a retrograde fashion declined along the total bullet path length of 8 cm. The fibre densities ranged between 53 fibres/cm near the exit site and 3 fibres/cm in the entrance region (Fig. 4a,b).

Crack length procedure

The crack length procedure demonstrated a minor increase of the cumulative crack lengths in all the investigated blocks from the entrance site to a bullet path length of about 16 cm followed by a steep rise of the crack lengths with maxima near the exit site between 20 and 23 cm away from the entrance site (Fig. 5).

High-speed video documentation

In the high-speed video documentation of a test shot to a 25-cm-long skin-gelatine composite model of series 1, the formation and extension of the temporary cavitation could be visualised (Fig. 6). It showed the development of a cylinder-shaped cavitation immediately behind the projectile temporarily extending from the entrance to the exit site, which then further expanded in the distal third of the bullet path. The maximally expanding section of the temporary cavity corresponded in its position with that part of the bullet path in which the longest cracks were measured. The primary cavitation was followed by further pulsations of declining intensity.

Discussion

In the four test series with test shots into gelatine composite models, we were able to demonstrate that textile fibres from the entrance and exit regions are transferred into the bullet track both in an anterograde and a retrograde fashion. The distribution patterns were largely identical for the two investigated fabrics, whereas the absolute figures of the displaced fibres were higher for the shots to jeans material than for those fired at jersey material.

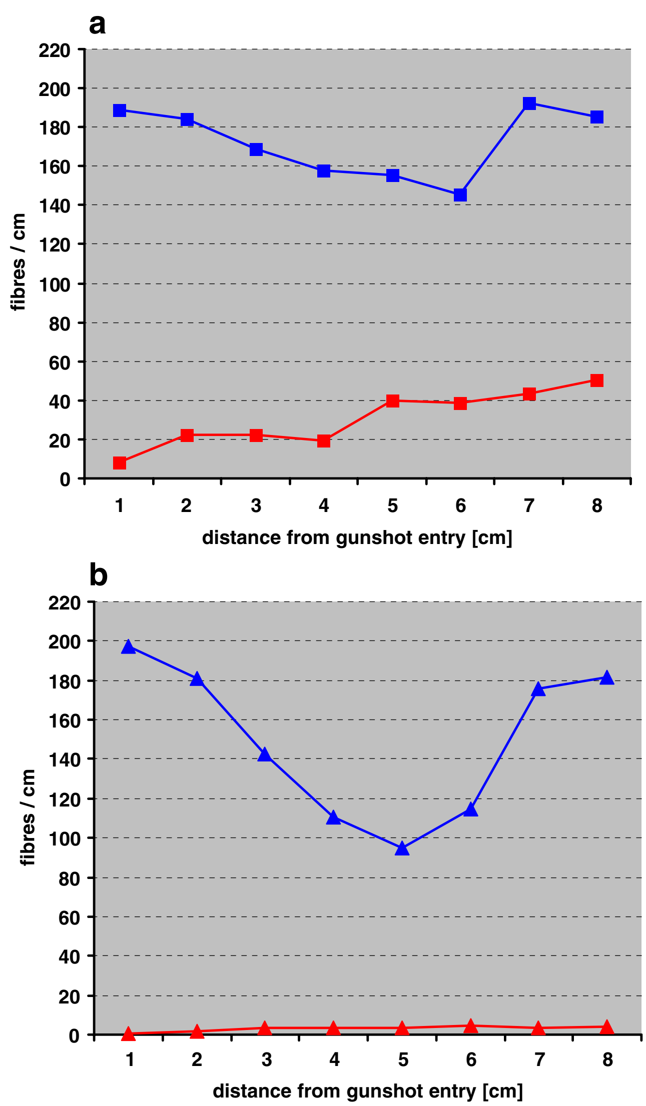


Fig. 4 Diagram of the mean values of fibre density in the bullet track for test shots to 8-cm-long composite models. *Blue curves*: fibres displaced from the bullet entrance site. *Red curves*: fibres displaced from the bullet exit site. **a** Fibre distribution with jeans material. **b** Fibre distribution with jersey material

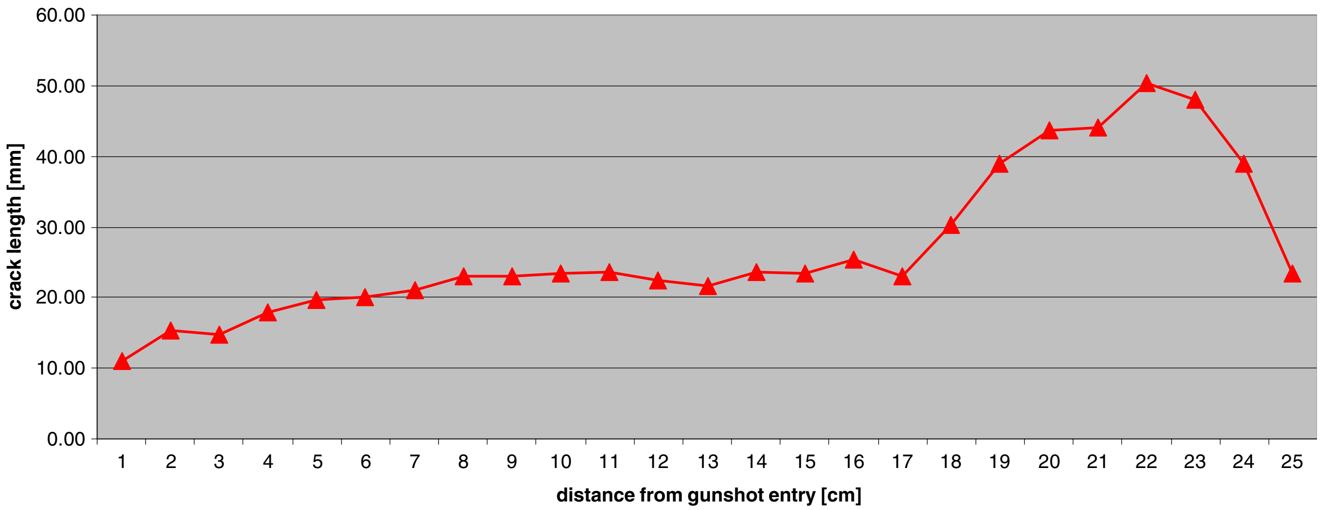
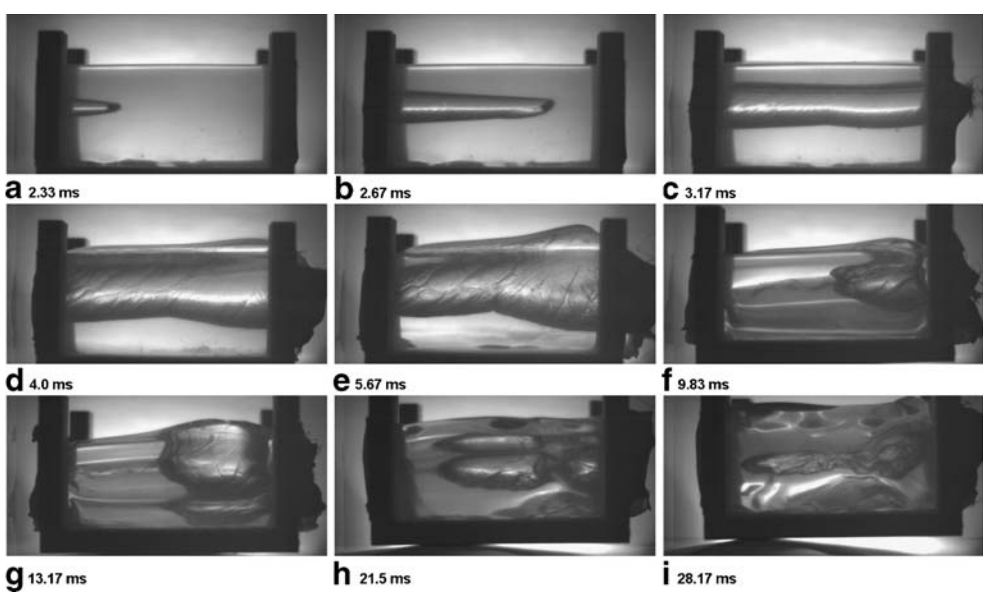


Fig. 5 Sum of all crack lengths in three gelatine blocks of test series 1 and 2 (mean values)

The number of fibres from the exit region displaced back into the bullet path was highly dependent on the length of the bullet track. At a bullet path length of 25 cm, there was a clear maximum near the exit and a declining fibre density towards the entrance site. These results are consistent with the distribution of bacteria applied to the skin of the exit region before the test which were found along the bullet path in previous studies [19]. Those studies confirmed the assumption that the retrograde transfer is caused by the suction effect of the temporary cavity. By determining the crack lengths (Fig. 5) and with the help of the high-speed video documentation (Fig. 6), it could now be demonstrated that under the experimental conditions of series 1 and 2, the maximum extension of the temporary cavity was localised in the distal third of the bullet path. When the length of the bullet track was reduced to 8 cm (test series 3 and 4), the cavitation was considerably less pronounced, the number of fibres displaced in a retrograde direction was very small, and the distribution along the bullet track was almost uniform. These results prove that the extension of the temporary cavity and the associated suction mechanism are responsible for the retrograde displacement of fibres from the clothing.

Our results show that the presence of textile fibres is not a suitable criterion to distinguish a gunshot entrance from an exit wound, as was claimed by Straßmann in 1919 [16]. Especially when firing shots at jeans material, the density of

Fig. 6 Sequence of a high-speed video documentation for a test shot of series 1 (6,000 fps, time in ms). **a**–**c** Development of a cylinder-shaped cavitation temporarily reaching from the entrance to the exit site. **d**, **e** Maximum expansion of the cavitation near the bullet exit site. **f**–**i** Further pulsations of the cavitation with declining intensity



textile fibres displaced in an anterograde and retrograde fashion was comparable (Fig. 1a). Straßmann [16] had only covered the skin of the bullet entrance region with woollen fabric and found a high fibre density in the vicinity of the entrance, but not at the exit when analysing the bullet tracks.

In the present paper, we were able to demonstrate that textile fibres are transported into the bullet track both from the entrance and the exit site, provided that both the entrance *and* the exit regions are covered by textile material — as is the case in most real gunshot injuries. Contrary to Sellier [13] and Owen-Smith [10] who thought that retrograde transfer of textile fibres is possible only with HV projectiles, we were able to prove that for shots from a conventional handgun, fibres are also transported from the exit site back into the bullet track. When covering only the bullet entrance region with fabric labelled with technetium-99m, Teige et al. [17] found out that the distribution of radioactivity in the gelatine medium (as an indicator for displaced fibres) depends on the kind of textile material, the bullet type and velocity and the length of the bullet track.

The presented study results confirm that not only skin contaminated by bacteria, but also displaced fibres from the clothing must be considered as a source of infection in gunshot wounds. Bacterial infection is a complication often seen in the clinical treatment of (primarily) survived gunshot injuries [2, 6, 18].

Conclusions

- Although textile fibres from the bullet entrance site show the highest concentration near the entrance, they occur along the entire length of the bullet track.
- Fibres of textiles covering the exit site are predominantly found in the distal part of the bullet track, but are seen along its entire length.
- The phenomenon of a retrograde displacement of fibres from the clothing back into the bullet track is not limited to shots with HV ammunition.
- Differentiation between gunshot entrance and exit wound by means of displaced textile fibres is problematical.
- Textile fibres from the bullet entrance and exit site may both cause bacterial infections of gunshot wounds.

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