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ORIGINAL ARTICLE

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Backspatter from experimental close-range shots to the head

I. Macrobackspatter

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Abstract Backspatter is the ejection of biological material from a gunshot entrance wound against the line of fire. This phenomenon was investigated experimentally in transverse gunshots to the heads of calves (n = 9) using two types of 9 mm Parabellum ammunition from shooting distances of 0–10 cm. The resulting bloodstains were documented on white paper placed horizontally 60 cm below the impact site. In this report the analysis was restricted to stains with a diameter > 0.5 mm. Backspatter was documented after every gunshot. The number of stains varied from 31–324 per gunshot and appeared to be independent of the shooting distance. The maximum distance droplets travelled varied from 72–119 cm. The majority of droplets accumulated between 0 and 50 cm. The number of droplets and the distances travelled should be higher in man for anatomical reasons. The direction a single droplet can take comprises every possible angle between the most tangential ones to the skin surface. This resulted in a semi-circle of 180° covered with stains. Skin ruptures of the entrance wound were not observed. The succession of events was documented on high speed film and started with the recoil of the firearm, immediately followed by a blow-out effect of the skin. Large droplets exited approximately 0.7–4 ms after the bullet impacted the skin. The calculated minimum initial velocity of these droplets was 13–61 m/s. Backspatter from gunshots to the head likely is caused by the hot gases expanding subcutaneously and by cavitation-related intracranial overpressure and tail splashing. In three out of nine gunshots, secondary backspatter additionally occurred as a result of droplets produced by a stream of blood from the entrance wound impacting the paper surface.

Key words Backspatter · Blood droplets · Blood stain morphology · Close-range shots to the head · Gunshot wounds · Reconstruction

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Introduction

A century ago, Hans Gross (1894) was one of the first to realize the forensic significance of bloodstain patterns in crime scene reconstruction. Despite research since then (e.g. Ziemke 1914; Lochte 1932; Balthazard et al. 1939; MacDonnel 1982; Brinkmann et al. 1985, 1986; Pizzola et al. 1986a,b), there is still a general lack of knowledge of blood drop dynamics (Pizzola et al. 1986a). The morphology of stains was a neglected area of criminalistics (Kirk 1967) and still is. This is especially true for bloodstains caused by gunshot wounds. In most perforating gunshot wounds, blood and tissue is ejected from the exit wound. In some gunshot wounds, biological material is also propelled retrogradely out of the entrance wound towards the firearm. This phenomenon has been recognized for a long time as "Rückschleuderspuren" (Hofmann 1898; Fraenckel and Straßmann 1924; Werkgartner 1924) and was later named backspatter (MacDonell 1982; Stephens and Allen 1983).

The stains resulting from backspatter can be important in crime scene reconstruction. Because of the direction against the line of fire, backspatter can be found inside the barrel, on the outside of the weapon, on the person shooting and on persons or objects in the vicinity. Determination of the weapon used and the person firing, the shooting distance or the posture of the victim can assist in the differentiation between suicide and homicide and also in the investigation of homicides.

The occurrence and the quantity of backspatter depend on a variety of ballistic and anatomical parameters. Backspatter is reported to occur with a close-range shot (Fraenckel and Straßmann 1924; Weimann 1931; Stephens and Allen 1983; Pex and Vaughan 1987; Burnett 1991), a gunshot into a liquid-filled cavity inside the body (Weimann 1931; Wagner 1963), a large-caliber bullet (Weimann 1931; Stephens and Allen 1983) and due to a bony abutment immediately beneath the skin assisting the development of a pocket-like subcutaneous space (Weimann 1931; Stephens and Allen 1983; Burnett 1991).

In case of gunshots to the head, backspatter is reported to result from either a rapid expansion of gas trapped between the elastic skin and the skull with a resulting backwards stream of escaping gas (Fraenckel and Straßmann 1924; Werkgartner 1924; Weimann 1931; Stephens and Allen 1983; Pex and Vaughan 1987) or from high intracranial pressures caused by temporary cavitation (Weimann 1931; Sellier 1982). The spin of the bullet (Wagner 1963) or a momentary suction effect of the barrel aspiring material into the muzzle (Brüning and Wiethold 1934; Knight 1977) do not contribute to backspatter (Sellier 1982).

Surprisingly little is known about the morphology and the extent of the backspatter stains and even less about the underlying physical, anatomical and ballistic parameters (Stephens and Allen 1983). Case reports (Fraenckel and Straßmann 1924; Weimann 1931) only throw some light on the topic. Mock experiments using primitive "head-models" constructed from blood-soaked sponges wrapped in plastic, rubber or tape (Stephens and Allen 1983; Pex and Vaughan 1987) resulted in small droplets from contact or almost contact shots only. The droplets travelled a maximum distance of 30–60 cm. But these findings are not reliable because there is neither a confined subcutaneous space for the hot gases to expand, nor is there a rigid skull to give rise to the high intracranial pressures during the formation of the temporary cavity. This applies even more to gunshots into soft pine covered with polyurethane foam saturated with blood (MacDonell 1982).

Only controlled animal experiments interpreted by comparison with man can produce reliable results. Burnett (1991) has used pigs for the investigation of microscopic bone and bone-plus-bullet particles in backspatter but neglected blood. MacDonnel (1982) performed shooting experiments on dogs but did not give detailed results or the experimental set-up. By shooting rabbits with a 7.65 mm pistol, Wagner (1963) lacerated the small animals rather than creating backspatter.

In this report, we will concentrate on the distribution and dynamics of macrobackspatter/droplets of blood on a plain surface. Macrobackspatter is defined as stains with diameters larger than 0.5 mm and is arbitrarily separated from spray/aerosol stains (stain diameter < 0.5 mm) for practical and analytical reasons. The distribution of microbackspatter will be reported on in connection with the morphology of the single stains.

Materials and methods

The experiments were conducted outdoors at a shooting range but the experimental set-up was protected by a tent. Live New Jersey calves ($n = 9$) of approximately 140 kg weight, 5–6 months old and all destined for slaughter, were shot into the right temple while standing in a metal cage. The body was fixed by bars while the head was free to move. Prior to the shooting, the thick hair in the temporal region had been completely shaved. A 9 mm SIG P210 pistol was placed perpendicular to the right temple 10 cm horizontally behind the right eye. A veterinarian licensed to perform livestock slaughter simulated a conventional shot with the right hand while kneeling in front of the calf, but the shooting was actually remotely triggered by a high speed camera.

The resulting backspatter, apart from that on the veterinarian's body surface and the firearm, was documented on thick white paper placed on the ground in front of the impact site. Ground level was about 60 cm below the entrance wound (Fig. 1). After each gunshot, the paper was collected and examined in the laboratory. The gunshots were followed by complete autopsies of the heads including the dissection of skin, soft tissue and bone at the entrance site, removal of the brain and examination of skull and brain.

Two different kinds of ammunition were used: a conventional 9 × 19 mm Parabellum (= Luger) full metal jacket (FMJ) round (7.5 g) produced by AMA and a 9 × 19 mm Parabellum Action-1 round produced by Dynamit Nobel (non-jacketed solid copper-alloy bullet, 5.4 g, Fig. 2). Each bullet was fired from 4 different distances: tight contact (the muzzle placed with pressure against the skin), loose contact (the muzzle just touching the skin), 5 cm and 10 cm. Perforating bullets were caught in a bullet collector made of stapled cardboard. A total of nine gunshots was fired to the heads of nine animals.

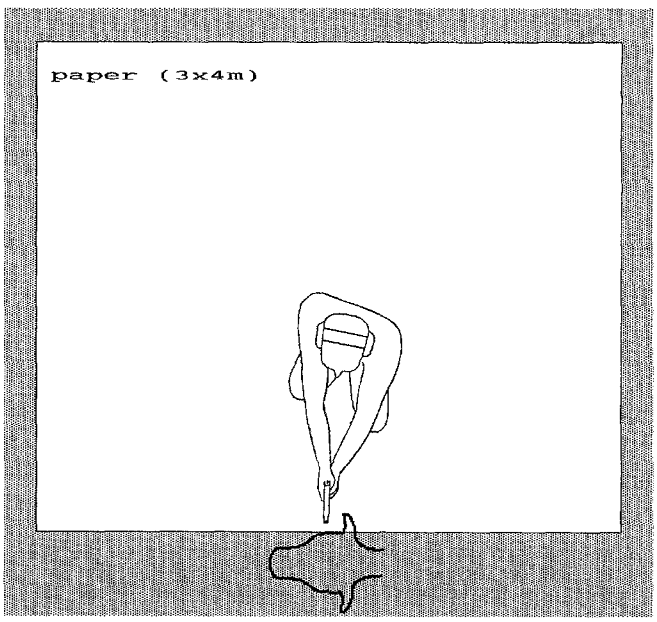

Fig. 1 Scheme of the experimental set-up

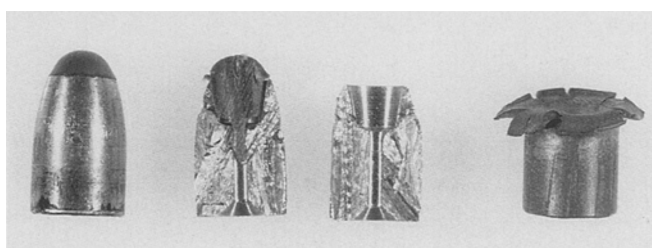

Fig. 2 Action-1 bullets from left to right: an unfired bullet, cross sections of unfired bullets with and without plastic cap and a fired bullet after recovery from soft tissue. The small central channel and the cavity in the tip are filled with ballistic plastic which separates from the projectile inside the ballel when fired

The muzzle velocity of both projectiles was measured by Doppler Radar consisting of an ED 900 transmitter/antenna and a DR 5000 Velocity Analyzer (Knudsen and Svender 1994). An average muzzle velocity was calculated using ten gunshots from the same pistol and the same lot of ammunition. The events at the impact site were filmed with a high speed camera (Hycam 30 m) at a rate of 8000 pictures per second using a Kodak 2253 16 mm × 38.1 m high speed daylight film. The camera was positioned 2.5 m in front of the animals and perpendicular to the bullet trajectory. The films were postprocessed using a CCD-videocamera (Panasonic WV CD22) and a microscopic measurement table (Leitz-Latimed). Time and distance were measured with a X-Y videomicrometer (Deininger KG) by utilizing the rate of 8000 pictures per second, a time-marker and a scale on the films. The velocities of the droplets were calculated from these measurements.

Results

Dissection of the heads revealed that the skin at the impact site was approximately 2 mm thick. The entrance wounds formed round holes without any cruciform or stellate rupture of the skin. There was a muzzle imprint in the contact shots. The temporal skull forms a bony channel enclosing a large Musculus temporalis (Fig. 3). So the bullet passed through 3–4 cm of subcutaneous tissue and muscle before penetrating the skull, which measured 5–7 mm at the impact site. The sutures were closed but represented points of mechanical weakness. Indirect skull fractures, which were present in every case, were restricted to the sutures. All trajectories entered the skull at the bottom of the bony channel in the right temporal region and followed a transverse course through the brain. The brain volume varied between 400 and 500 cm^3 and the heads were 17–21 cm wide at this point.

After each gunshot the animal collapsed immediately and agonal convulsions started 30–60 seconds later. On the high speed films, no systematical movement of the heads in the direction of the line of fire was visible during the first 50 ms after impact. Movement in any direction did not exceed 10 mm.

The mean muzzle velocity from 10 gunshots was 372 m/s (minimum 368 m/s, maximum 379 m/s) for the FMJ bullets and 432 m/s (minimum 415 m/s, maximum 449 m/s) for the Action-1 bullets. All FMJ bullets perforated the heads without deformation or fragmentation. None of the Action-1 bullets exited and were located either below the skin or lodged in the bone at the exit side.

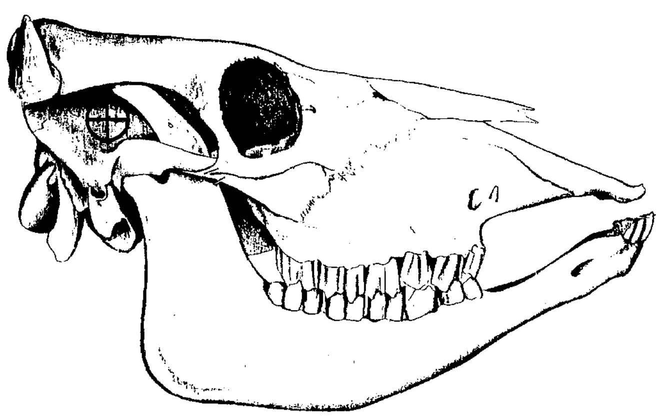

Fig. 3 The skull of a calf. The mark indicates the impact site at the bottom of the bony channel in the temporal region, which is filled with a large Musculus temporalis

Evaluation

Stains from backspatter were present after every gunshot. Apart from small bone fragments and tiny pieces of soft tissue, the main part of backspatter was blood consisting of an aerosol/spray and droplets, which were separated in this study by a stain diameter of 0.5 mm. With regard to the mode of formation, two types of droplets/macrobackspatter stains can be differentiated:

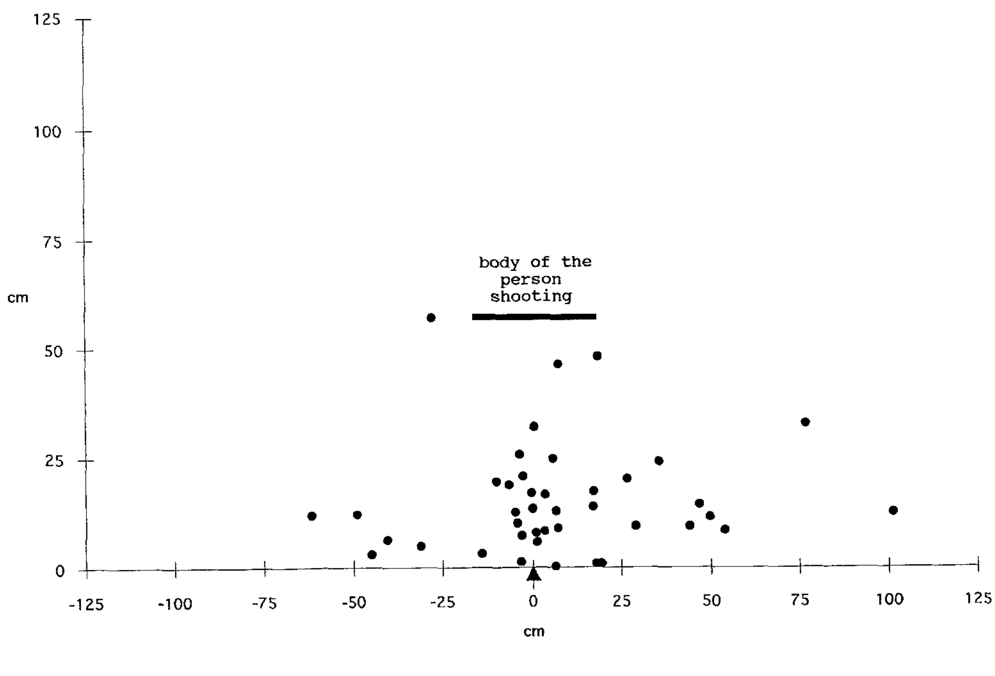

Fig. 4 The distribution of primary droplets on a horizontal surface in front and 60 cm below the entrance wound from the tight contact shot using Action-1 ammunition. The arrow indicates the location of the entrance wound

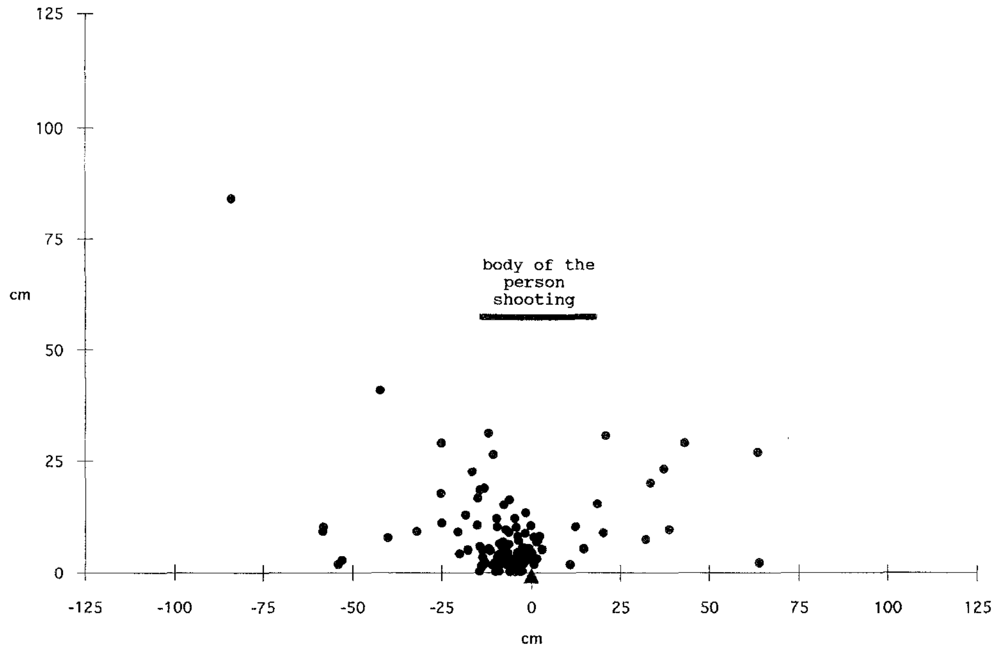

Fig. 5 The distribution of primary and secondary droplets on the horizontal surface from the tight contact shot using a FMJ bullet

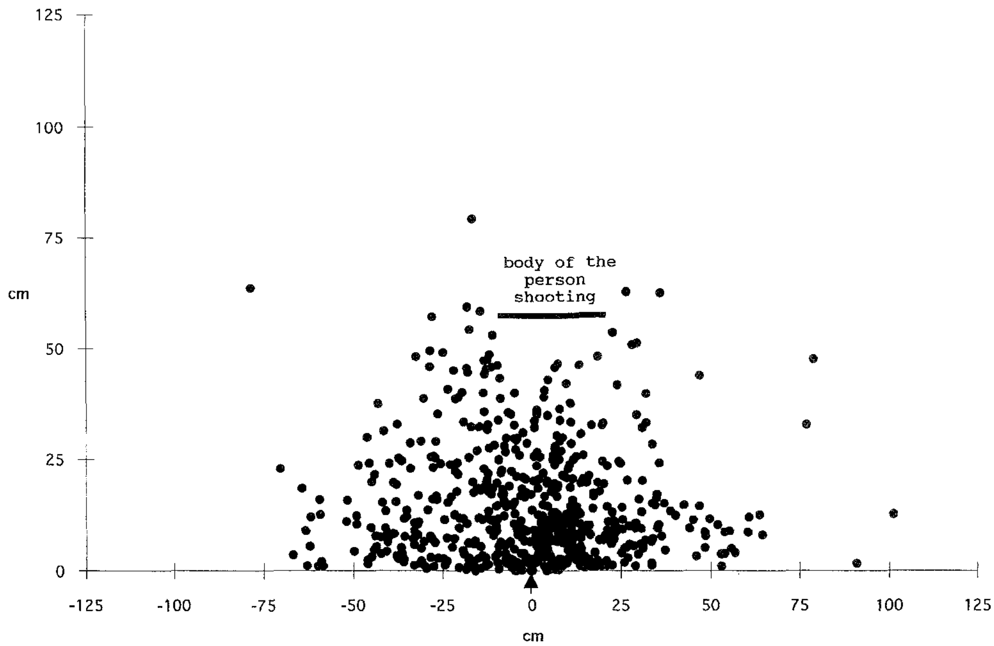

Fig. 6 The superimposed distribution of the resulting primary bloodstains on the horizontal surface 60 cm below the entrance wound for six out of nine gunshots. In these six gunshots primary backspatter was exclusively produced

Primary backspatter

The droplets originated from the entrance wound and hit the surface directly without interference with an intermediate target (Fig. 4).

Secondary backspatter

After a short time interval of less than one second (the high speed film had ended), blood poured out of the entrance wound for a moment and then suddenly stopped. This blood hit the paper approximately 10 cm in front of the entrance wound, creating a pool of blood surrounded by secondary droplets (Fig. 5). Primary backspatter was present after every gunshot (Fig. 6), secondary backspatter additionally occurred in three out of nine gunshots (Fig. 7).

In the six gunshots exclusively producing primary backspatter, the number of primary bloodstains amounted to 592 (mean value 99 bloodstains) with a maximum of 324 and a minimum of 31 (Table 1). Presuming otherwise identical conditions, the number of primary bloodstains did not decrease with increasing shooting distance and the FMJ bullet caused more bloodstains than the Action-1 bullet (Table 1), but the small number of gunshots investigated does not allow a statistical evaluation.

The distance the primary droplets travelled before hitting the paper surface varied between 0 cm and 119 cm (Fig. 8). The maximum distances in single gunshots varied

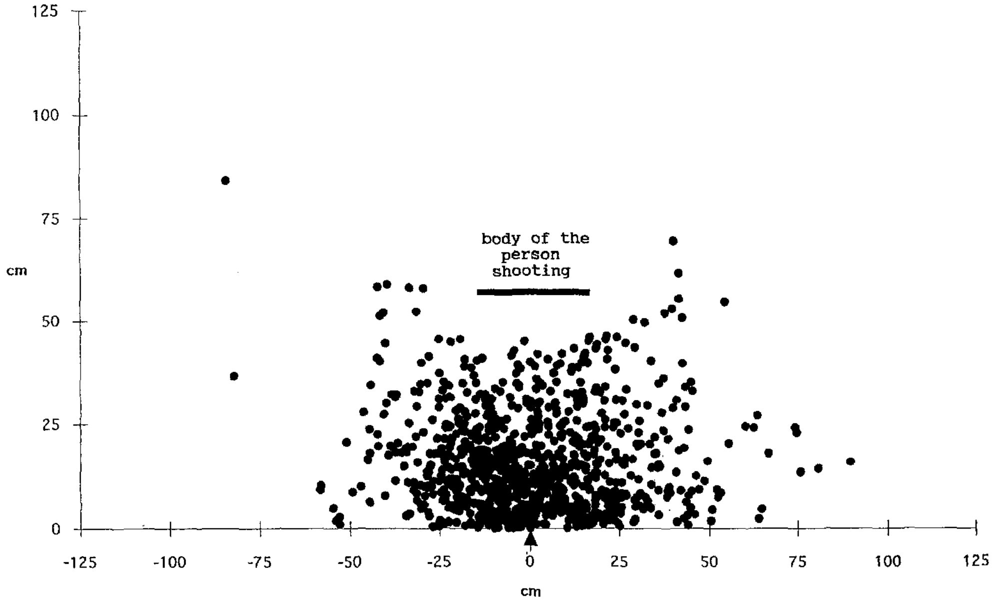

Fig. 7 The superimposed distribution of the bloodstains caused by the three gunshots which additionally caused secondary blood flow and secondary droplets. The respective pools of blood are not shown because these would overlay the stains caused by the other two gunshots

Table 1 A summary of ballistic parameters and results for all nine gunshots. The maximum distances the droplets travelled is given in cm. * indicate the three gunshots including secondary backspatter

Ammunition	Shooting distance	Number of bloodstains	Maximum distance
FMJ	Tight contact	133*	119
FMJ	Tight contact	324	101
A-1	Tight contact	41	102
FMJ	Loose contact	51	81
A-1	Loose contact	31	72
FMJ	5 cm	99	91
A-1	5 cm	46	92
FMJ	10 cm	305*	80
A-1	10 cm	478*	91

between 72 cm and 119 cm (Table 1). The vast majority of droplets accumulated between 0 cm and 50 cm (Fig. 8). This accumulation was a constant finding after every single gunshot. For single gunshots, the distribution of the droplets was not even or constant (Fig. 4). In a summarized presentation of all six gunshots (Fig. 9), the distribution of the bloodstains is more regular with a maximum tangential to the skin surface on both sides and a minimum in the direction of the firearm. This minimum was caused by the veterinarian in the shooting position. The shape of the surface covered with primary bloodstains resembles a semi-circle with the impact site in the middle of the base line (Fig. 6).

The sequence of events could be determined by close examination of the post-processed high-speed films. The first event to take place was the recoil of the firearm,

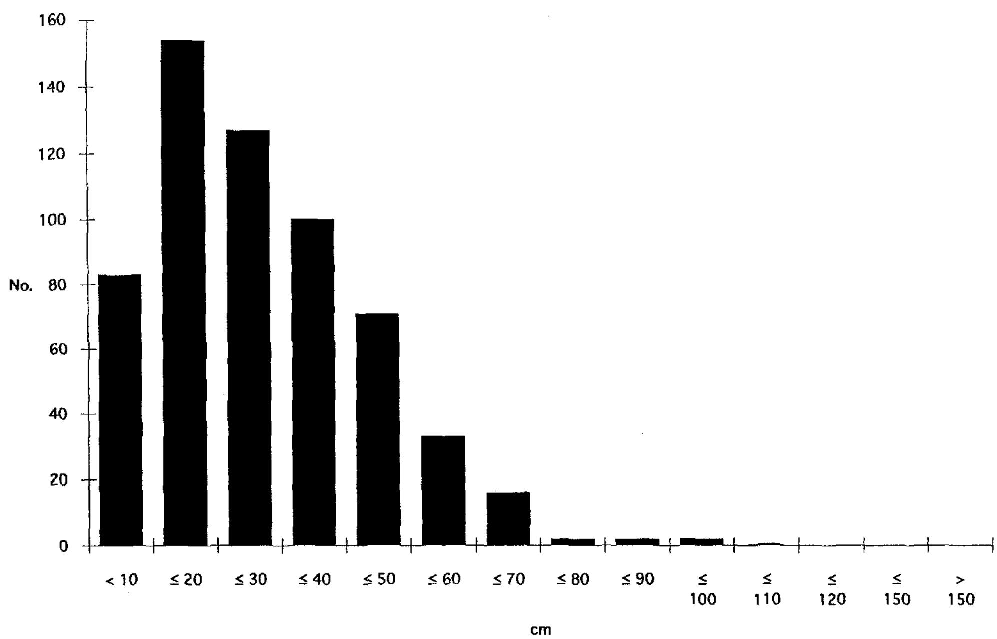

Fig. 8 A summarized presentation of the distances the primary droplets travelled in the six gunshots exclusively producing primary backspatter

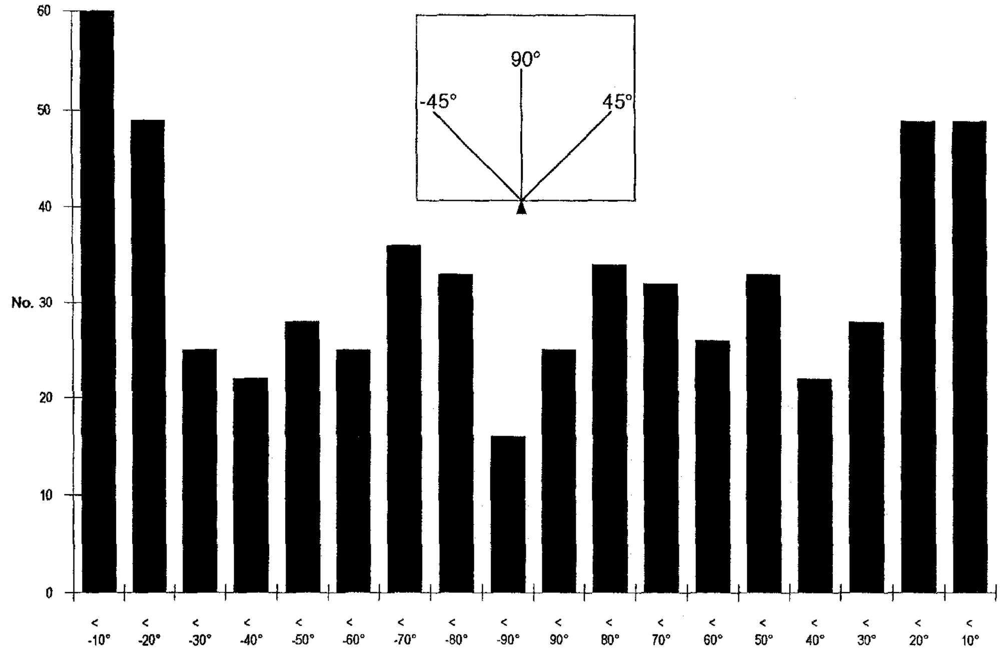

Fig. 9 A summarized presentation of the directions the single primary droplets took for the six gunshots exclusively producing primary backspatter. The insert explains the meaning of the angles with the arrow indicating the entrance wound

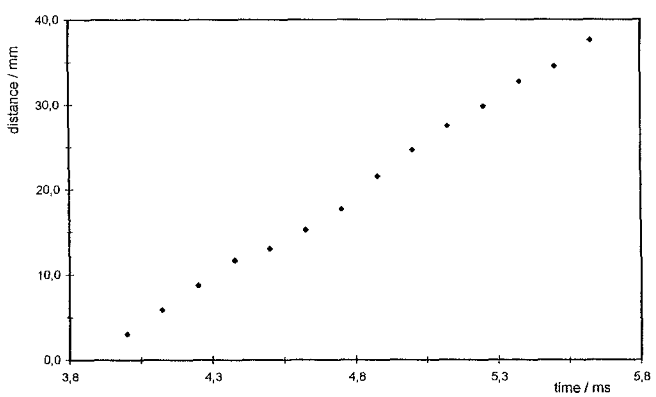

Fig. 10 The movement of the third droplet during the first 3.7 cm

which started moving the muzzle backwards and upwards immediately after the bullet left the barrel. The angle between the long axis of the barrel and the trajectory regularly amounted to 134°–142°, the velocity of the muzzle during the first 5 cm of this movement was calculated to be 2.8–3.6 m/s. Next a discrete "blow-out" of the skin around the entrance wound became visible even when the shooting distance was 10 cm but skin lacerations did not occur. This expansion of the skin started immediately after the bullet penetrated the skin and lasted for about 3 ms.

The following of individual droplets on the high speed films was difficult. On the film of the gunshot using Action-1 ammunition from a distance of 10 cm, we were able to identify and follow three large droplets of 1–3 mm in diameter. The first droplet originated from the entrance wound 0.7 ms after the bullet impacted the skin, the second and the third had a latent period of 1.6 ms and 4 ms, respectively. The droplets travelled inside a cloud of escaping gases and smaller droplets. The initial velocities calculated from the films were 61 m/s, 13 m/s and 21 m/s, remaining almost constant over the short distance (22 mm to 46 mm) the droplets could be followed (Fig. 10). The velocities represent a minimum value because of the three-dimensional movement being reduced to the two-dimensional film.

Discussion

Bloodstained shooting hands, especially from suicidal gunshots to the head, are a well-known finding (e.g. Weimann 1931; Knight 1977; Sellier 1982; DiMaio 1985). In every day life, an object hitting a liquid surface can generate droplets splashing in the direction from which the object came. In terminal ballistics, backward hurling ("tail splashing") of gelatin (Black et al. 1941; Herget 1953) and isolated muscle (Amato et al. 1974) and backward fragmentation of glass (Lamprecht 1959; Thornton 1974; Sellier 1982) and bone inside soft tissue (Lorenz 1948) are well documented. Additionally, high speed photographs of bullets impacting skin revealed "backspatter" of tiny skin particles exiting between the penetrating tip of the bullet and the skin (Sellier 1969, 1982). The skin particles did not produce visible stains except for the abrasion ring, which is caused by those particles tangentially hitting the edge of the entrance wound (Sellier 1969, 1982).

There are three possibilities for the origin of the physical forces producing primary backspatter: subcutaneous gas effect, temporary cavitation-related intracranial pressure and tail splashing. The muzzle pressure of 9 mm Luger ammunition reaches approximately 150 bar (15 000 kPa) (Sellier and Kneubuehl 1994) immediately after the bullet leaves the barrel. The peak intracranial pressure caused by a 6 mm steel sphere (450 m/s) was measured to be 4.3 bar (430 kPa) directly underneath a gelatin-filled human skull (Watkins et al. 1988) and the maximum temporary cavitation lags for 2–4 ms (Callender and French

1935; Harvey et al 1945; Scott 1983). Tail splashing, which is likely caused by the backwards streaming of fluid and tissue particles along the lateral surface of the bullet during penetration of a dense medium (Herget 1953), has been documented as early as 0.2 ms after impact (Black et al. 1941) and may be considered an early stage of temporary cavitation. In our observations on droplet dynamics, the first drop originated 0.7 ms after the bullet impacted the skin. Consequently, the hot gases expanding subcutaneously probably supply stronger driving forces for the ejection of backspatter in contact shots but the time of ejection does not allow a differentiation between the underlying physical forces. The presence of backspattered brain particles in cases described by other authors (Brüning and Wiethold 1934; Zwingli 1941) can only be explained by intracranial temporary cavitation. Thus, the subcutaneous gas effect may be the major factor responsible for backspatter in close range shots to the head, but cavitation-related pressures and tail splashing can also be important, as has been demonstrated in a case of a gunshot to the heart from a distance of 4 m resulting in massive backspatter travelling up to 2.5 m (Weimann 1931).

The thickness of the calf's skin and skull at the impact site is similar to man. The brain volume is almost half that of man, which for the calf will likely result in higher intracranial overpressures (Watkins et al. 1988). The layer of temporal soft tissue in man is approximately 1 cm deep but in calf the same layer measures 3–4 cm. The temporal channel, although confined on two sides by bony walls, provides a larger volume for the hot gases to expand. Therefore, the subcutaneous pressures caused by the hot gases will presumably be lower compared to man. To this anatomical difference we attribute two findings deviant from man: the lack of substantial pocket-like underminings surrounding the entrance wound and the lack of radial skin lacerations in the calves.

Despite the reduced subcutaneous gas effect, every gunshot produced a considerable amount of primary backspatter. The number of primary droplets and their travelling distances would probably have been greater if the gas effect would have been as strong as in man. Accordingly, the maximum distances observed (up to 119 cm) can be clearly exceeded in human fatalities. In a recent suicide, we measured a backspatter travelling distance of 2 m after a frontal contact shot with .22 High Velocity rimfire ammunition. The victim had been sitting in the back of a van and the droplets hit the rear door up to a height of 60 cm. Findings from the scene including the primary stain pattern verified that the man had not moved after the gunshot.

The maximum shooting distance that produces backspatter in cases of gunshots to the calf head is likely more than 10 cm (Table 1). The maximum shooting distance for production of backspatter due to the gas effect will correspond to the maximum range of hot gas expansion in front of the muzzle, whereas backspatter produced by intracranial temporary cavitation and tail splashing will be independent of the shooting distance.

Due to the small number of gunshots, a statistical analysis was not performed. Consequently, a dependence of the number of primary bloodstains on the shooting distance or on the type of ammunition cannot be statistically evaluated but in the few gunshots investigated, FMJ bullets did cause more droplets than Action-1 bullets (Table 1). Since the propellants from both rounds (FMJ and Action-1) are similar (manufacterer's specifities, DNAG), differences in the design of the bullets may be responsible for this. The plastic cap and central post of the Action-1 bullet separates from the bullet already inside the barrel and the bullet deforms in tissue to a mushroom-like shape, as shown in Fig. 2 (Sellier and Kneubuehl 1994; manufacterer's specifities, DNAG). Either, hot gases will precede the Action-1 bullet through its empty central channel before it leaves the barrel, which will lead to a smaller amount of gas entering the wound, or the expanded tip of the bullet hampers the backwards streaming of fluid and tissue particles along the lateral surface of the bullet, thus reducing the amount of tail splashing.

The direction of primary droplets can comprise every possible angle inside a hemisphere with the impact site in the centre of the complete sphere. On a horizontal surface beneath the entrance wound, the stains cover a semicircle (Fig. 6) and not a triangle as assumed by MacDonell (1982). The distribution of the droplets from a single gunshot on this surface is usually uneven and asymmetrical (Fig. 4). However, in a summarized presentation the pattern is more symmetrical and even except for an accumulation in the tangential sectors close to the base on both sides (Fig. 9). This accumulation might be due to the muzzle partially obstructing all but the tangential angles before the recoil has moved the muzzle away from the entrance wound. As radial skin ruptures did not occur even in tight contact shots, these are not a prerequisite for the occurrence of primary backspatter. If skin ruptures do exist, they might cause an accumulation of droplets towards the side of their occurrence, thus contributing to non-random, asymmetrical distributions.

The individual droplets observed on the high speed film were large compared to the majority of primary droplets. Although their sizes were similar, the respective velocities differed considerably. An explanation is that the subcutaneous gas pressure and the temporary cavitation are not static but change continuously with the lapse of time and at different locations. This leads to varied kinetic energies transferred to individual droplets, which depend on both the time and location of droplet ejection. Because of the small mass and the high frontal surface area of droplets we had expected a considerable deceleration in the beginning of the trajectory. Since the velocities remained virtually constant during the first few centimeters (Fig. 10), the backwards stream of hot gases could have a contrary effect by dragging the particles along after exiting from the entrance wound, thus interfering with their free flight. A few short-distanced fluctuations around the constant velocity (Fig. 10) may reflect turbulences in the backwards stream of gases.

The origin of the wound bleeding in three of the calves cannot be completely explained. It may be from a lacerated artery and perivascular pressure increase could be a contributing factor. The differentiation of primary from secondary bloodstains was unproblematic close to the pool of blood but became more difficult and sometimes uncertain with increasing distance. In casework, the surfaces hit by primary and secondary backspatter are usually not as ideal as in our series. The resulting bloodstain patterns will therefore be more complex, especially if a superimposition of secondary and primary backspatter has to be considered. The firearm or the shooting hand are less likely to act as intermediate targets for secondary backspatter because of the delay relative to the recoil.

Conclusions

Results of this study should have practical relevance for the work on actual cases:

1. Primary backspatter can exit in every gunshot to the head from close-range (up to 10 cm), possibly from longer distances. The number of primary stains larger than 0.5 mm in diameter was substantial: 31–324. The number of primary droplets did not decrease with increasing shooting distance.

2. The maximum distance primary backspatter can travel is considerable. In this experimental set-up the maximum distance was 119 cm but for anatomical reasons, this distance, as case work suggests, is greater in man. The vast majority of droplets accumulated between 0 and 50 cm.

3. On a horizontal surface, stains from primary backspatter cover a semi-circle. The distribution of stains inside this semi-circle was uneven and asymmetrical in single gunshots perpendicular to the head and in the absence of skin ruptures.

4. Skin ruptures are not a prerequisite for the occurrence of backspatter. Such ruptures likely will cause non-random, asymmetrical distributions of the resulting stains.

5. The succession of events started with the recoil of the firearm and was immediately followed by a "blow-out" of the skin. Large primary droplets exited 0.7–4 ms after impact of the bullet and had initial velocities ranging from approximately 10–100 m/s. Backspatter is a dynamic and variable phenomenon: droplets of similar mass exited at different times and with different velocities.

6. In a minority of gunshots to the head, secondary backspatter follows primary backspatter after a short interval when a swell of blood from the wound impacts on the floor.

Other aspects of backspatter such as an analysis of angled trajectories and longer shooting distances have not been addressed. Additional research will be necessary in order to better understand backspatter.

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