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ORIGINAL ARTICLE

Wounding capacity of muzzle-gas pressure

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Abstract
Background Suicidal gunshot wounds that are caused by ammunition fired from a 9-mm Luger pistol, with direct contact between the gun muzzle and the victim's head, present a serious injury pattern even with full metal jacket bullets. Wound ballistic experiments were performed to clarify whether muzzle gases from the firearm have an additional wounding potential.
Methods Fifteen head models were prepared as follows: an acryl sphere measuring 14 cm in diameter was completely covered with a layer of silicon that was 3 mm thick. These spheres were filled with 10% gelatine. At 4°C, these models were fired at with a 9-mm Luger pistol, loaded with Quick Defense 1 expanding bullets. Five shots were fired with direct muzzle contact, one shot was fired from a distance of 10 cm, four shots were fired from a distance of 2 m, and five shots were fired from a distance of 4 m.
Results Each projectile penetrated the model; all but one projectile deformed regularly. Each acryl sphere shattered into comminuted pieces but was held together by the silicon cover. The gelatine filling was then cut into slices 1 cm thick, and each slice was optically scanned. An evaluation was performed following both Fackler's Wound Profile method and the polygon procedure method. The pattern of gelatine disruption did not differ in shots from intermediate ranges, but the amount of gelatine destruction was always more extended in the case of muzzle contact shots. Depending on the section of the bullet path, crack lengths were 31% to 133% longer in contact shots. The first centimetre and the second half of the bullet path showed the greatest increase.
Conclusion The experimental findings prove the wounding capacity of muzzle gases.

Keywords Suicide · Craniocerebral injury · Gunshot wound · Head model

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Introduction

Suicidal gunshot wounds of the head are generally inflicted by holding the firearm directly against the skin of the head [1, 2]. Calibres from .32 up show contact gunshot wounds with a characteristic star-like disruption of the skin and an undermining of soft tissues [2–4]. In corresponding autopsies, the medical examiner may detect soot deposits under the periosteum [5] or on the dura mater. Gunshot residues (GSR) within the cranial cavity indicate that muzzle gas has possibly been blown in. However, the question whether muzzle gas has an additional, detrimental effect cannot easily be answered by autoptic practice. The wound track of the head mainly lies within the brain, which contains very soft tissue. In addition, the tissue damage is submerged in a wide haemorrhage. Thus, comparing measurements in situ cannot be performed, but a wound ballistic study could analyse the questioned phenomenon.

Animal head models are suitable for backspatter research [6, 7] but inappropriate for wound ballistic analyses. Thali et al. proposed a head model made by a hollow sphere of polyurethane filled with ballistic gelatine [8]. The surface was industrially coated with a very thin latex film

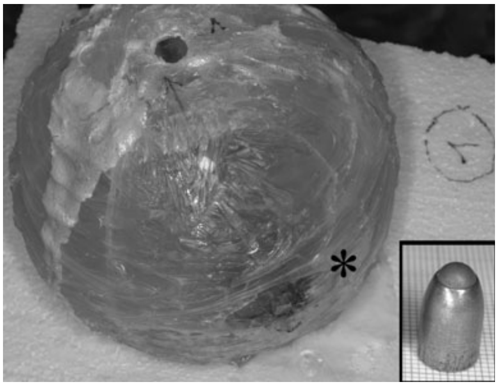


Fig. 1 Head model No. 1, muzzle contact shot (*). The *arrow* on top of the sphere indicates the shooting direction. This marking was necessary if shots were fired from a distance with a missing GSR deposit. Above the *arrow*, the filling hole is visible. The image in the corner shows an unfired Quick Defense 1 bullet, including the typical red plastic ball within the hollow point

representing the periosteum. A silicone cap was used to simulate the skin. However, this model had several disadvantages concerning our project. The gelatine mass weighed about 2.9 kg, which exceeds normal brain weight, and there was no tough scalp keeping the bone model together. Furthermore, the Synbone® (Switzerland) polyurethane hollow sphere was very expensive. Therefore, an alternative model [9, 10] based on an acryl hollow sphere with a diameter of 14 cm was chosen. A series of 15 shots—10 from various distances and 5 with muzzle contact—were fired and then compared with each other.

Material and methods

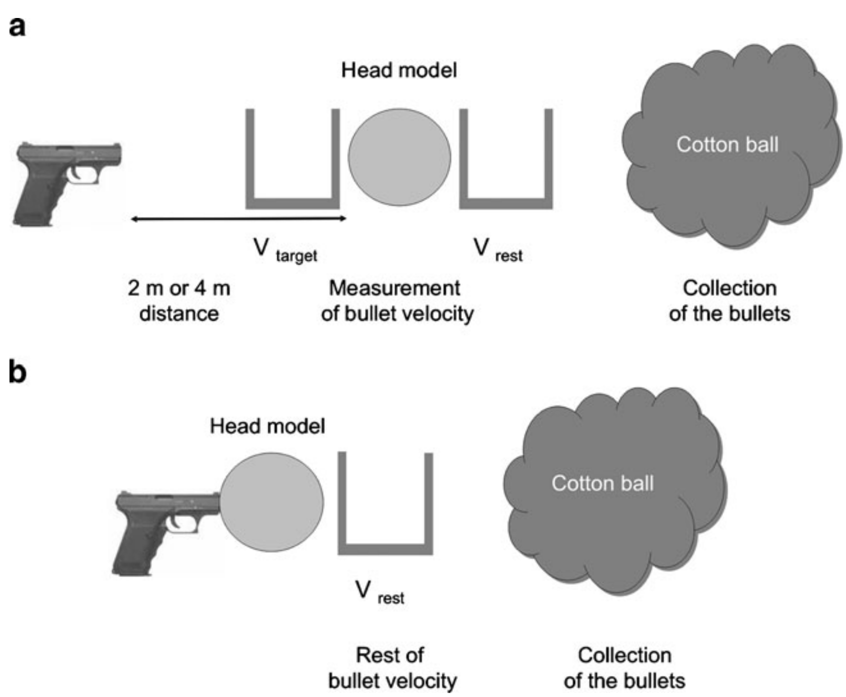
Head model

Two transparent acryl hemihollow spheres, each 14 cm in diameter and each with a wall thickness of 2 mm, were glued together and allowed to dry for one day. After that, each sphere was manually and completely covered with 230 ml of transparent silicone (for construction purposes), resulting in a coat of about 3 mm thick. The freshly coated sphere was then glued on a slightly excavated polystyrene plate. The connection line of the hemispheres was oriented vertical to the polystyrene base. The sphere was then allowed to dry for 2 more days and then weighed while empty. Following Fackler's instructions [11], 10% standard gelatine (GELITA Ballistic I, Germany) was prepared. A 12-mm hole was drilled on the top of each sphere (Fig. 1), and the sphere was then filled with the gelatine solution using a funnel. After at least 48 h of storage at 4°C, the complete head model was weighed.

Shooting

A semiautomatic P7 pistol (Heckler & Koch, Germany), 9-mm Luger (9×19 mm) in calibre, was used as a weapon. In order to dissipate as much kinetic energy as possible within a relatively short head model (with a bullet track of about 14 cm), Quick Defense 1 ammunition (M.E.N., Germany) was chosen (Fig. 1). Each copper hollow point bullet weighed 5.8 g and was recognized as expanding reliably.

Fig. 2 **a** Drawing of the experimental setting for shots fired from distances of either 2 or 4 m. **b** Drawing of the experimental setting for shots with either muzzle contact or a 10-cm distance



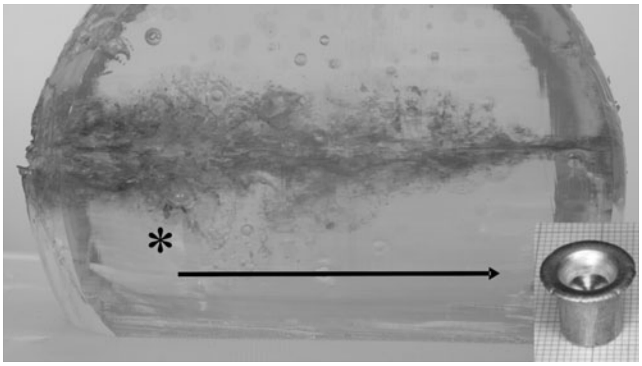


Fig. 3 Contact shot to head model No. 1. The gelatine core shows sooty deposits at the beginning of the bullet track. The shooting direction was from left to right. The plastic material (*) of the red ball was contained in the hollow point of the bullet. The image in the corner shows the mushroomed projectile after the loss of the red ball

All of the models were cooled to 4°C. Two shooting series were performed. When shots were made from distances of 4 and 2 m, a speed-measuring device (a photoelectric barrier BMC 18 Mehl, Germany), which was installed 25 cm in front of the target, recorded the velocity of the projectile. Behind the gelatine model, another speed-measuring device was installed to record the rest velocity of the bullets that penetrated the head model (Fig. 2a); this measurement failed in some cases because the bullets had lost too much kinetic energy and deviated without passing the second barrier of the BMC 18.

A second series of five shots were fired by holding the muzzle directly against the model (Fig. 2b). When possible, the rest velocity was measured.

After all test shootings, the bullets were captured in a cotton ball and were then recovered.

Evaluation

After shooting, the gelatine core was carefully removed from the sphere. The bullet track was photographed and cut into consecutive slices, each 1 cm thick. Images of the slices were taken by scanning (Epson Perfection 3200, Seiko Epson Corporation, Japan) at 300-dpi resolution. The images were then analysed on a personal computer with analySIS 3.2 software (Soft Imaging System GmbH, Germany). The following evaluation methods were applied:

- Fackler's Wound Profile (WP) method [12]

  The lengths of the two greatest cracks per slice were added together, and the results of all slices were added up for the entire model (the total damage).
- Polygon procedure (PP) [13–15]

  The ends of the tears were linked by lines creating a polygon. The polygon perimeter and area were measured as the values of the damage for each slice. The polygon parameters of all the slices were then added up for the entire model (the total damage). (Fig. 4)

Results

The head models contained a relatively regular filling of gelatine weighing about 1,340 g, which corresponds to the weight of a medium-sized male brain. Each shot caused comminuted fractures of the acryl spheres, but the silicone coat held the broken spheres together. Each bullet penetrated the head model. Each of them was mushroomed (Fig. 3), as expected, except the bullet in shot number 4. Bullet fragmentation was not noticed. When shots were made with direct muzzle contact to the head model, a relevant back-spatter (gelatine, acryl particles and GSR) toward the shooter was observed. Contact between the muzzle and the head model caused a laceration in the silicone at the bullet entry with soot deposit on the silicone and on its inner side, forming a cavity of soot. In distance shots, even with only a distance of 10 cm, an undermining of silicone was not detected. Shots with muzzle contact left sooty deposits along the bullet track that were macroscopically visible in the first and last quarters (Fig. 3). Figure 4 shows a contrasting of the tears in gelatine by sooty GSR.

Principal data of the shooting series are summarized in Table 1. In seven of the shots, the rest velocity of the bullet could be measured. The Quick Defense 1 bullet achieved

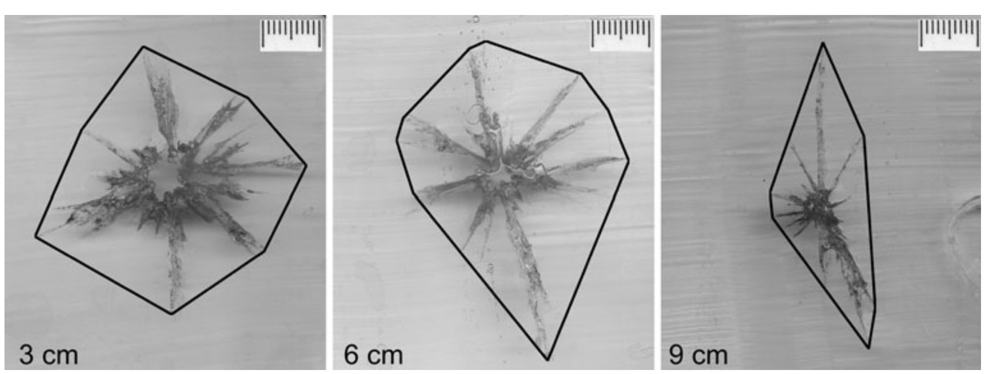


Fig. 4 Scanned slices of 1 cm thickness of a contact shot (3, 6 and 9 cm depth of bullet track number 8). Tears are contrasted with dark deposits. The bubbles are not in the gelatine but in the water fluid between the scanner and the gelatine. *Scale* 1 cm

Table 1 Principal data of the shooting series. Values in italics were estimated by averaging the measured target velocities

Test no.	Shooting distance (cm)	Bullet velocity		Dissipated energy		Diameters of the mushroomed nose			Model weight	
		v target (m/s)	*v* rest (m/s)	Joule	Relative (%)	D 1 (mm)	D 2 (mm)	Gelatine (g)	Empty (g)	Filled (g)
1	0					12.1	11.9	1,364	373	1,737
5	0					12.4	12.2	1,339	362	1,701
4	0					9.5	9.4	1,338	397	1,735
8	0	*393.1*	109.9	*413*	*92*	13.2	13.1	1,343	325	1,668
15	0	*393.1*	132.7	*397*	*89*	11.5	11.2	1,341	377	1,718
2	10					13.5	13.5	1,358	372	1,730
10	200	394.3	88.5	428	95	13.3	13.1	1,307	353	1,660
11	200	394.9	107.5	419	93	12.8	12.4	1,339	331	1,670
12	200	386.3	107.4	399	92	12.4	12.0	1,341	357	1,698
16	200	394.1	103.5	419	93	13.3	12.9	1,343	384	1,727
3	400	394.0				13.7	13.6	1,349	351	1,700
6	400	398.5	91.6	436	95	11.5	11.1	1,341	361	1,702
9	400	*393.1*	85.6	*427*	*95*	13.3	13.3	1,343	330	1,673
14	400	386.8	116.5	395	91	12.3	12.1	1,342	348	1,690
17	400	396.2	131.9	405	89	12.9	12.6	1,342	333	1,675

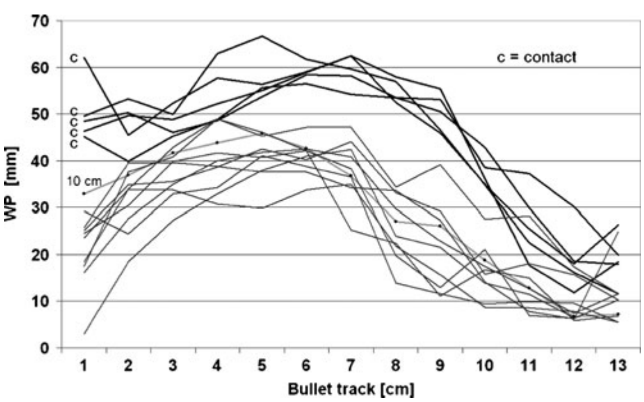


Fig. 5 Fackler's WP of all 15 shots, with visible differentiation between contact shots and distance shots

about a 90% energy transfer to the model, which corresponds to about 400 J.

An evaluation of the gelatine slices, according to Fackler's WP method, showed a clear difference between muzzle contact shots and shots fired from a distance (Fig. 5), but the shots from various distances (10 cm, 2 m and 4 m) did not differ significantly from each other. The absolute values of the total damage for all 15 shots are listed in Table 2. The WP of contact shots was 31% to 133% larger (mean 81%) than those of shots from a distance (Fig. 6 and Table 3). Overall, the greatest increase of the WP was observed in the first slice (+29 mm) and in depths from 7 cm (+21 mm), 8 and 9 cm (+29 mm) and 10 cm (+21 mm). When the PP method was used, results were similar. The polygon perimeter correlated with the

Table 2 Evaluation of the total damage in all 15 shots using the respective parameters

	Sum of Fackler's Wound Profile					Mean
Contact shot	559	577	593	596	592	583
2-m distance	379	283	335	336	345	336
4-m distance	367	383	297	447	280	357
	Sum of polygon perimeters					Mean
Contact shot	1,536	1,564	1,553	1,619	1,630	1,580
2-m distance	999	772	857	845	864	867
4-m distance	869	889	797	1,033	766	871
	Sum of polygon areas					Mean
Contact shot	11,734	12,268	12,240	12,363	13,997	12,520
2-m distance	5,235	3,283	3,736	3,394	3,168	3,763
4-m distance	3,797	3,722	3,484	4,554	3,505	3,812

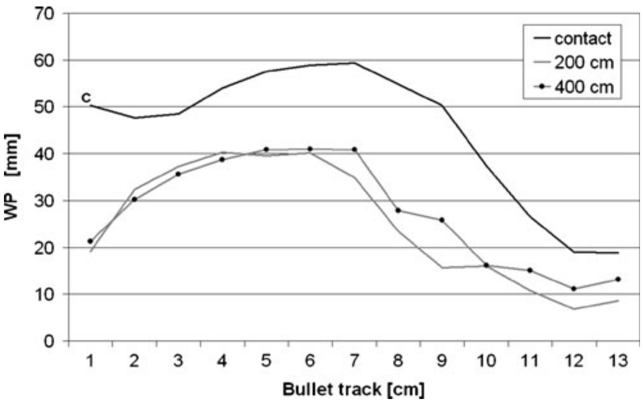


Fig. 6 Mean values of the WP for diverse distances

WP. Contact shots had 45% to 140% higher values than distant shots. In comparison to distance shots, the polygon perimeter of contact shots was, in the mean, twice as much (Table 3). The relatively greatest increase was observed in the first centimetre and in the second half of the bullet path where, typically, the transfer of kinetic energy is lower than in the phase of the bullet deformation between 1 and 7 cm. The polygon area, which represents the disrupted area in the gelatine, best documents the significant difference between shots with and without distance (Fig. 7). Because the area is a two-dimensional parameter, the values of contact shots are, in the mean, four times higher compared to those shots fired from a distance (Table 3). Interestingly, contact shot number 4, where the deformation of the bullet remained incomplete, did not cause a significantly different destruction pattern or amount.

Table 3 The difference between contact and distant shots along the bullet track is shown by the ratio of each parameter. The mean values of five contact shots and ten shots from a distance were calculated for each slice corresponding to a 1-cm bullet track. Values greater or equal to the median are printed in bold type

	Destruction ratio contact to distant shot		
Bullet track (cm)	Wound profile	Polygon perimeter	Polygon area
1	**2.33**	**2.36**	**5.15**
2	1.50	1.62	2.69
3	1.31	1.45	2.29
4	1.36	1.45	2.40
5	1.41	1.56	2.87
6	1.44	1.60	2.93
7	1.56	1.83	3.78
8	**2.11**	**2.29**	**5.77**
9	**2.31**	**2.40**	**5.58**
10	**2.29**	**2.40**	**5.72**
11	**2.02**	**2.08**	**4.86**
12	**2.13**	**2.07**	**4.19**
13	**1.80**	**1.96**	**3.98**
Median	1.80	1.96	3.98
Mean	1.81	1.93	4.02

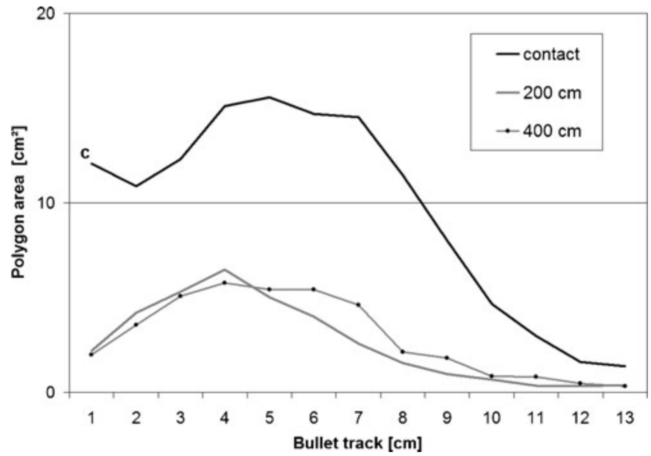


Fig. 7 Evaluation of the disrupted area using the PP method. Mean values of each distance series are shown

Discussion

In cases of forensic autopsies of suicides with gunshots to the head where a 9-mm Luger weapon was used, the medical examiner may conclude that there was immediate incapacitation. In general, in these cases, indirect bone fractures (particularly of the skull base) are observed. Apart from direct tissue crushing, the most important aspect of wounding might be the energy transfer to the brain tissue by cavitation, but this cannot be the only aspect. Verhoff and Karger [16] described the case of a suicide with a 9-mm Quick Defense PEP (PolizeiEinsatzPatrone) bullet which caused an atypical gunshot entrance wound and extensive backspatter. The authors discussed the additional effect of expanding muzzle gases. Although 9-mm full metal jacket bullets penetrated the head within contact shots, extended skull-base fractures were found even though the calculated deposit of kinetic energy was relatively low. In addition, several medical examiners have documented GSR findings along the bullet track in the cases of contact shots made to the head. Therefore, a systematic wound ballistic experiment using an adapted head model was performed. In order to produce the greatest possible tissue disruption by energy transfer, Quick Defense 1—an expanding bullet—was chosen. A comparison of contact shots and shots from an intermediate range clearly showed that gelatine disruption was significantly more extended in contact shots. The five experiments with muzzle contact showed GSR along the bullet path, particularly in the first and last parts, which corresponds to findings by Lieske et al. [17] and is systematically documented by quantification of GSR by Große Perdekamp et al. [18]. A distance of 2 or 4 m and also 10 cm to the model already changed the character of the gelatine destruction. Of course, the additional wounding capacity of muzzle-gas pressure depends on the load of the cartridge. Karger [19] published a review of suicidal gunshot wounds to the head where a lack of incapacitation was observed, especially concerning cartridges of low-gas pressure with .22, .25 or .32 calibres. Still, there are cases of successful suicides with blank cartridge guns pressed against the head [20]. The dangerous pressure of blank cartridges was illustrated recently by systematic measurements of the 9×17 mm cartridge [21].

Conclusion

It was demonstrated that gunshots with direct muzzle contact to the head model show a higher wounding capacity than shots from an intermediate range with the same ammunition. The detrimental effect of muzzle-gas pressure corresponds to observations in forensic autopsies.

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