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ORIGINAL ARTICLE

Visualization of the powder pocket and its influence on staining in firearm barrels in experimental contact shots

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Abstract The powder pocket or soot cavity is a morphologic characteristic of a close contact shot. In a research project concerning staining inside the barrel, the influence of the powder pocket on these traces was investigated.

According to the 'triple contrast method', thin pads containing a mixture of acrylic paint, radiocontrast agent and blood were glued on plastic boxes which were coated with a 3–4-mm-thick silicone layer. The containers filled with 10 % ballistic gelatine, were stored for at least 60 h at 4 °C. Thirty-three contact shots were realized using different pistols and 22 lr, .32 auto, .38 special and 9-mm Luger with different barrel length using subsonic, non-deforming ammunition.

The documentation comprised endoscopy, high speed video and computer tomography (CT) of the target models. Using image analysis, the ballooning of the silicone coat was studied (lateral view projection).

High-speed video confirmed the actual comprehension of the behaviour of muzzle gases in contact shots. The powder cavity rises in about 1.5 to 2 ms, preceding the maximum of the temporary cavity, and the powder pocket's collapse takes 2.5 to 3 ms.

The size of the silicone dome increased with decreasing barrel length. Comparing semi-automatic pistols of 4 in. barrel length in the calibres, .32 auto and 9-mm Luger, there were no significant differences of the powder pocket size. Material transport was observed, against and perpendicularly to the shooting direction. CT showed undermining and gas inclusions inside the powder pocket. A correlation between amount and pattern of the staining inside the barrel and the volume of the powder pocket was not observed.

Keywords Suicide · Contact shot · Powder pocket · Soot cavity · Backspatter

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Introduction

Contact gunshot wounds are mainly found in suicide cases. Own experiences [1, 2] are confirmed by literature [3–5]. In the majority of cases, suicidal gunshots concern the head with preference of the temple region [3, 6, 7]. The morphology of contact shots is different to shots from intermediate or distant range, because the injury is not only caused by the bullet but also by muzzle gases. By pressing the muzzle on the skin, the expanding gases are forced to penetrate tissue. If the skin overlies bone, gases penetrate subcutaneous tissue and expand between soft tissue and bone so that the skin is ballooned and pressed against the weapon's muzzle. The skin is stretched beyond its elasticity and tearing in split, stellate or cruciate form. In autopsy, we find gunshot residues deep within the lacerated tissue and even under the periosteum [8]. Another indicator for the expansion of gases under the skin is the cherry-red coloration of muscle tissue by carbon monoxide [9–11]. This subcutaneous zone is called powder cavity or soot pocket (French "chambre de mine").

During experimental contact gunshots on silicone enveloped models for backspatter analysis [12], ballooning of the silicone coat could be observed. Hence, the question resulted if this effect is reproducible and if a correlation between muzzle gas pressure and volume of the powder cavity can be identified. If applicable, what is the influence of the powder pocket's size on the staining inside the barrel?

Materials and methods

Target models

Following the triple-contrast method' [12], heparinized blood of the adult, informed and consenting volunteers was mixed with acrylic paint (CPM, Erkrath, Germany) and barium sulphate-based radiocontrast agent Micropaque® (Guerbet, Brussels, Belgium) and sealed into thin 5 × 5 cm^2 foil bags. These bags were glued on (model A) respectively, under (model B), the lid of a plastic box (12 cm × 10 cm × 9 cm). All models were covered with a 3–4 mm thick layer of silicone and stored at 4 °C for 16 h. Finally, a 1-liter, 10 % gelatine 'Ballistic III' (Gelita, Eberbach, Germany) was filled into the boxes and the models were stored at 4 °C for another 48 h. The contact shots were documented with high-speed videography (20.000 fps, SA-X2, Photron Europe Ltd., West Wycombe, UK). After shooting, the models were scanned with a CT Somatom Definition AS 64 (Siemens, Germany) using the following settings: 100 kV, 120 mA, slice 0.6 mm, increment 0.4 mm, kernels J30 s and H70-h extended CT-scale. The image analysis was performed using multiplanar reconstruction on a Syngo CT workstation (Leonardo).

Weapons and ammunition

Common revolvers and semi-automatic pistols were used in the forensically relevant calibres such as .22 long rifle, 7.65-mm Browning (.32 auto), 9-mm Luger and .38 special. To minimize the differences between the calibre 9-mm Luger and .38 special subsonic cartridges with the same bullet weight of 10.2 g were chosen. All bullets were non-deforming. Table 1 lists the weapons used in this study. After each shot, the barrel was inspected using a rigid borescope [13] and the staining inside was visually evaluated.

Image analysis

High-speed videos were converted to avi-files and sequences of frames were exported to tga-files. Using Photopaint 12 (Corel, Ottawa, Canada), the tga-files were converted to scaled tif-pictures. The picture showing maximal ballooning of the silicone coat was overlaid with the picture before shooting as reference (Fig. 1). These scaled pictures were analysed using AxioVision Rel. 4.7 (Zeiss, Oberkochen, Germany). Parameters were the profile of the area of the ballooning (lateral view projection), its perimeter and its maximum extension (height of the vertex) (Fig. 2).

Results

The presented study comprised 33 close contact shots on silicone-coated plastic boxes, each filled with 1-liter ballistic gelatine. All shots were recorded perpendicularly to the bullet track by a high-speed video in which a significant ballooning of the silicone coat could be observed (Figs. 1–3, Fig. suppl. 1). By image analysis, the side view projection of the ballooning was evaluated (Table 1). The measurements were performed several times by different examiners without important differences.

Analysis of the high speed image sequences (20.000 fps) has shown that the maximum of ballooning is not exactly coincidental with the maximal height which can be reached some frames later. The shots in the .22 long rifle calibre showed a large range of powder pocket sizes. Their maximum appeared on average after about 1.5 ms. In the 7.65-mm series, the evolution of the maximal ballooning took 1.5 ms (Beretta Mod. 70) to 2 ms (Cěska VZOR 70) and its collapse about 2.5 ms (Fig. 3). Using the 9-mm Luger pistols and .38 special revolvers maximal ballooning was observed after about 2 to 2.5 ms. Sometimes the escape of muzzle gases interfered with the sight, but did not prevent image analysis (Figure suppl. 1).

Model A (paint pad outside the model) showed good reproducibility for shots with different 7.65-mm Browning pistols, 32.1 to 39.8 cm^2. Two 9-mm Luger pistols with similar barrel length (4 in.) induced 37.1 and 40.9 cm^2 ballooning. However, the 7.65-mm Geco cartridge (RUAG, Fürth, Germany) contained 0.13 g powder, the 9-mm Luger subsonic cartridge (Fiocchi, Lecco, Italy), 0.26 g powder. The volume of the 9-mm, 4-in. barrel is about 38 % greater than the 7.65-mm barrel of the same length. This consideration could help in understanding why the two cartridges present only a slight difference of muzzle gas effect.

38 special lead round-nose revolver ammunition was tested with four revolvers of different barrel length (Fig 4). The influence of the barrel length on the muzzle gas action is clearly visible. The Sellier&Bellot (Vlašim, Czech Republic) cartridge contained 0.31g powder, generating bullet velocities from 231 to 238 m/s in the revolvers up to 4-in. barrel length. The Magtech cartridge (Lino Lakes, USA) containing 0.24 g powder was chosen for the 6-in. barrelled revolver (229 to 232 m/s).

Model B (paint pad inside the box) worked well as model A. With the short barrelled weapons, the ballooned area was inferior to that in model A (Fig. 4). However, the characteristics remained the same as in model A. Using the 6-in. revolver or the 5-in. pistol, no significant difference of the models A and B could be noted.

Table 1 Weapons and ammunitions used, staining inside the barrel and measurements of the expansion of the powder cavity

Weapon	Calibre	Type of weapon	Cartridge	Bullet weight [g]	Barrel length [mm]	Target Model	Staining	Ballooning of the silicone coat			
								Area [cm^2]	Median	Perimeter [cm]	Height [cm]
Arminius HW5	.22 WMR	Revolver	.22 long rifle HV CCI	2.6	100	A	0	2.2		13.3	0.6
			.22 Stinger CCI	2.6		A	+	7.5		16.4	1.5
Walther PP Sport	.22 long rifle	Semi-automatic pistol	.22 long rifle CCI	2.6	98	A	++	17.7	19.6	20.3	3.0
				2.6		A	+++	21.4		21.9	3.6
			.22 long rifle HV CCI	2.6		A	++	29.3	33.6	23.7	4.2
				2.6		A	++	37.9		26.5	5.3
Beretta Mod. 70	7.65-mm Browning	Semi-automatic pistol	7.65-mm FMJ Geco	4.75	90	A	++	35.5	33.4	25.4	4.7
SIG P230				4.75	92	A	+++	32.2		26.0	4.5
Cěska VZOR 70				4.75	96	A	+++	39.8		27.0	5.1
Walther PP				4.75	98	A	+++	32.4		24.8	4.5
FÉG				4.75	100	A	+++	34.3		25.1	4.3
FN 1922				4.75	113	A	+++	32.1		25.4	4.6
S&W Mod. 5906	9-mm Luger	Semi-automatic pistol	9-mm Luger FMJ Fiocchi	10.2	100	A	+++	40.9	36.7	26.6	5.1
						B	+++	36.3		26.2	5.1
Beretta 92 FS compact	9-mm Luger	Semi-automatic pistol	9-mm Luger FMJ Fiocchi	10.2	100	A	+++	37.1		26.2	4.5
						B	+++	29.0		25.3	4.3
Beretta 92 FS	9-mm Luger	Semi-automatic pistol	9-mm Luger FMJ Fiocchi	10.2	125	A	+++	39.4	33.3	27.4	6.0
						A	++	30.8		24.0	4.4
						B	+++	30.4		24.2	4.5
						B	++	35.8		26.7	4.8
S&W Chief special	.38 special	Revolver	.38 special LRN S&B	10.2	45	A	++	76.7	61.1	35.2	8.2
						A	++	56.3		30.7	7.0
						A	++	65.8		32.0	7.9
						B	++	53.7		30.1	6.1
S&W Mod. 686–3	.357 Magnum	Revolver	.38 special LRN S&B	10.2	75	A	+	45.0	40.9	28.6	5.8
						B	+++	36.8		28.3	5.4
Astra Cadix	.38 special	Revolver	38 special LRN S&B	10.2	100	A	+++	35.0	32.6	25.2	5.0
						A	++	32.6		24.3	4.9
						B	+++	26.4		23.1	4.3
Ruger Security-Six	.357 Magnum	Revolver	.38 special LRN Magtech	10.2	150	A	+++	30.0	31.5	23.8	5.0
						A	++	32.9		23.7	4.9
						B	++	28.0		24.5	4.7
						B	++	33.0		23.8	5.0

SIG Schweizerische Industrie-Gesellschaft, Neuhausen, Switzerland, *FÉG* Fegyver- és Gépgyár, Budapest, Hungary, *FN* Fabrique Nationale d'Armes de Guerre, Herstal, Belgium, *S&W* Smith and Wesson, Springfield, USA, *S&B* Sellier&Bellot, Vlašim, Czech Republic, *HV* high velocity, *FMJ* full metal jacket, *LRN* lead round nose

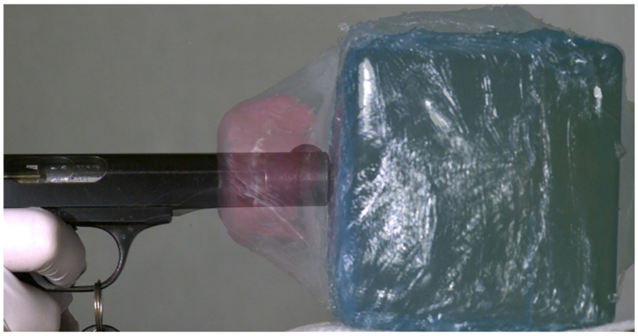

Fig. 1 Semi-automatic pistol FN 1922, calibre 7.65-mm Browning. The image of maximal ballooning of the silicone coat is overlaid with the initial position of the firearm

In CT-scans of the target models, the collapsed cavity was visualized. As expected inclusions of gas were found under the silicone coat, within the boxes and inside the bullet track (Fig. suppl. 2). The X-ray contrast material was found spread within the powder pocket even in the model B where the paint pad containing barium sulphate was placed under the lid of the box (Fig suppl. 2, 5). Contrast material was displaced in fine cracks of the powder pocket against gravity.

Endoscopy revealed characteristic staining inside the barrels except for the small calibre revolver. The results given in Table 1 do not indicate a correlation of the powder pocket's size and the intensity of staining.

Discussion

The characteristics of suicidal gunshot wounds are well known and detailed descriptions are already found in the textbooks of the XIXth century. So Hofmann 1881 [14] and Vibert 1893 [15] described the role of the muzzle gases in contact shots to the head. Expanding gases are undermining tissue, detaching soft tissue from underlying bone and tearing the skin to stellate or lacerated wounds. In the textbook of Strassmann [16], the origin of the muzzle imprint is explained by the gas pressure pressing the skin against the weapon. Mueller and Walcher [17] outline the same mechanism as detachment of the skin from the bone during the formation of the soot cavity (German "*Schmauchhöhle*"). Simonin [18] describes the soot cavity, using the French term "*chambre de mine*", as anfractuous subcutaneous decollement lined by soot, debris, smear and powder particles mixed with blood. To this "*scollamente cutaneo*" refers Domenici [19] without giving an Italian name. In European literature, the phenomenon is called powder pocket or cavity [8, 20–28], whereas in Anglo-American handbooks no specific name is given [10, 29].

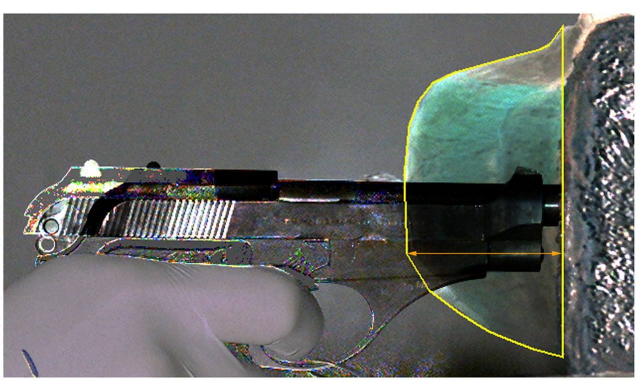

Fig. 2 Semi-automatic pistol Beretta, calibre 7.65-mm Browning. Process of image analysis using the overlaid pictures. The lateral view projection of the silicone dome is surrounded by a line, the height of the dome is indicated by an arrow. Note the motion of the slide, whereas the muzzle remains in initial position

The powder cavity is the compartment in which muzzle gases penetrate deeply in tissue, mobilizing tissue fragments and blood which are rejected in part against the shooting direction. In order to investigate the influence of the powder cavity on staining inside the barrels, a series of 33 contact shots on silicone coated models was performed and recorded with high speed video. In most of the tests, an impressive dome of the silicone coat was observed independently from the placement of the paint pad simulating the blood. Time analysis of the high speed sequences showed that the bullet had passed through the model less than 1 ms after ignition of the cartridge; whereas, the maximal ballooning occurred about 1.5 to 2 ms after ignition, and 2 to 3 ms later, the powder cavity had collapsed. In this study, the maximum expansion of the temporary cavity could not be observed because of the intransparency of the models. In comparably sized pure gelatine blocks, the maximally expanded temporary cavity was reached about 1 ms after the maximum of the powder pocket.

CT analysis of the target models showed the undermining of the silicone coat with gas inclusions and transportation of contrast agent in all directions, in and against the shooting direction and against gravity perpendicularly to the bullet path in cracks of the powder cavity.

The silicone ballooning varied less than expected (excluding the weak, small calibre ammunition). The main differences were observed between the short and the long barrelled revolvers. This confirms the inverse correlation of the barrel-length and muzzle-gas pressure described by Grosse Perdekamp et al. [23]. However, the difference between the calibre 7.65-mm Browning and the 9 mm weapons (9 mm Luger/ .38 special) with medium barrels was not significant. This could be explained by the greater volume of the 9-mm barrel given with the same length. Effectively, the skin lacerations observed in suicidal gunshots to the head are relatively similar for the 7.65-mm pistols, 9-mm Luger pistols and long barrelled .38 special revolvers, if non-deforming bullets were used. Although the silicone coat cannot simulate the properties

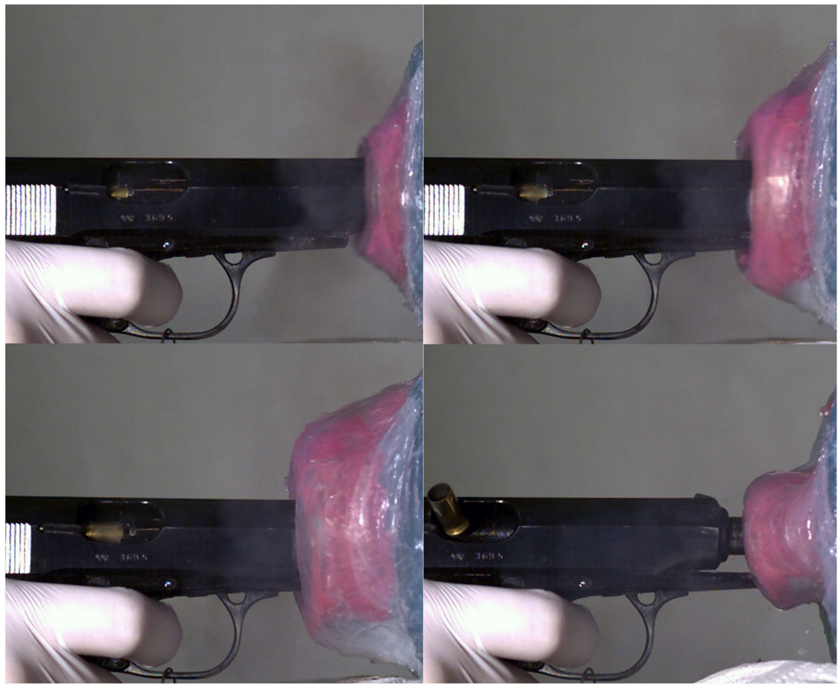

Fig. 3 Semi-automatic pistol FÉG, calibre 7.65-mm Browning. The images show the expansion and the collapse of the powder cavity at 0.8, 1.2, 1.9 and 4.9 ms

of human skin, extended detachments and skin tears of several cm length in suicide cases with comparable firearms, argue an analogous mechanism of bulging as in the wound ballistic model. In the present study, the influence of the bullet was minimized choosing non-deforming full metal jacketed or solid lead rounds with subsonic velocities.

The inspection of the barrel by endoscopy [13] revealed significant differences in pattern and amount of stains inside the barrel without correlation to the maximal volume of the powder cavity. The staining rather seems to depend on the type of weapon. These findings should be confirmed by further studies.

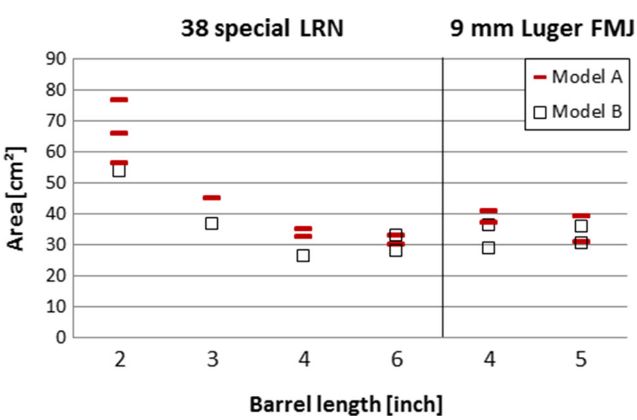

Fig. 4 Size of silicone dome in the nominal 9-mm calibre sorted by ammunition and differentiated by the barrel length. *FMJ* full metal jacket, *LRN* lead round nose

Conclusion

The powder cavity could be reliably visualized using silicone coated ballistic models. High speed video confirmed the actual comprehension of the behaviour of muzzle gases in contact shots.

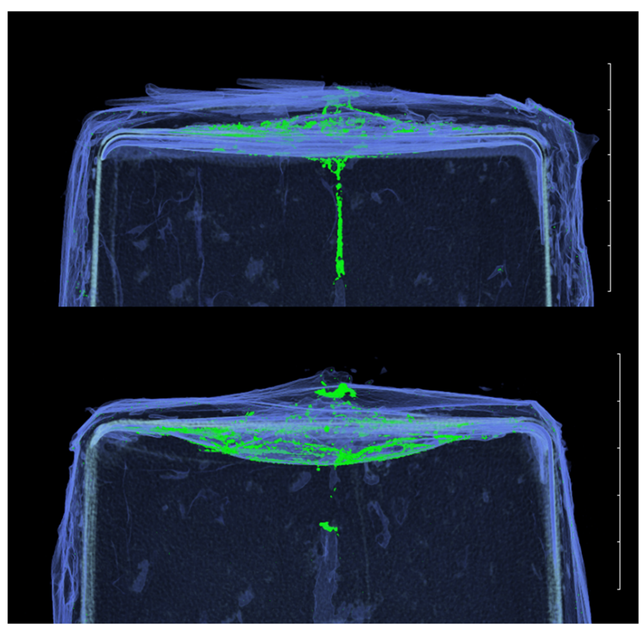

Fig. 5 Volume rendering of boxes after contact shot with 9-mm Luger rounds showing radiocontrast agent (bright spots) spread over and under the lid of the box independently from the placement of the paint pad. Above pad placed on the lid, below under the lid. Scale 5 cm

The powder cavity rises in about 1.5 to 2 ms, preceding the maximum of the temporary cavity. The powder pocket's collapse takes 2.5 to 3 ms.

The volume of the powder cavity decreases with increasing barrel length.

The differences in powder cavity size between 7.65-mm and nominal 9-mm calibre were slight using 4-inch barrels.

A correlation between the powder cavity size and the amount or pattern of staining inside the barrel was not observed.

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Compliance with ethical standards

Conflict of interests The authors declare that they have no conflict of interests.

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