Forensic Science, Medicine and Pathology (2018) 14:202–208
https://doi.org/10.1007/s12024-018-9971-0

ORIGINAL ARTICLE

Distortion of the temporary cavity and its influence on staining in firearm barrels

Christian Schyma [1] · Rolf Müller [2] · Eva Brenčičová [1] · Julia Brünig [1]

Accepted: 7 March 2018 / Published online: 3 April 2018

Abstract
After contact shots to the head, biological traces can be found inside the barrel of the firearm. Experimental protocols to generate this sort of staining, using 12 cm gelatin cubes containing thin foil bags filled with acrylic paint, human blood, and radiocontrast agent, have been developed. Previous research on shots fired at a distance has shown the underlay sustaining these gelatin cubes has an influence on experimental results. This study was conducted to investigate the role of the sustaining base of the gelatin blocks during contact shots, and its influence on the staining result inside firearm barrels. Eighteen contact shots were performed using 22 LR, 32 ACP (7.65 Browning) and 9 mm Luger semi-automatic pistols. With each pistol, shots were fired onto six gelatin cubes; three placed upon a rigid platform and three upon an elastic underlay. The shots were recorded by a high-speed video camera as they penetrated the gelatin cube. Any staining present inside the firearm barrels after the shots were fired was documented by endoscopy. Cross sections of the gelatin blocks were then compared to the high-speed video. It was found that the nature of the staining inside the barrel was not influenced by the underlay sustaining the target model. In the experiment using a 9 mm Luger, the rigid counterfort provoked a visible distortion of the temporary cavity, but, cross sectional analysis of the gelatin cubes did not reveal a relevant influence of the sustaining underlay on the crack length in the gelatin. This could be explained by a secondary expansion of the temporary cavity left by the projectile as a consequence of subsequent inflow of muzzle gases.

Keywords Suicide · Firearm barrel · Wound ballistics · Backspatter · Biological traces · Muzzle gases

Introduction

After contact shots to the head, mostly in suicide cases, biological traces can be detected inside firearm barrels using endoscopy [1, 2]. Through analysis of nucleic acids, it has been possible in previous studies to link the firearm to the victim (identification with STR) [3] and, in some cases, to specify the injured organ (miRNA pattern) [4]. However, in routine case work these findings vary widely. Therefore, systematic investigation through an experimental approach was necessary. Roughly simplified, three elements are indispensable: the gun, blood and a head model.

Human blood, donated by volunteers, is a prerequisite for performing PCR. Experimental contact shots have shown that blood can be detected inside firearm barrels by PCR [5]. Previously, a morphological assessment of these traces by endoscopy has not been practicable because of poor contrast qualities. Mixing blood with acrylic paint makes it possible to make the staining inside firearm barrels visible without inhibiting subsequent PCR. This liquid mixture of blood and paint was sealed in a thin foil bag and integrated in silicone coated, gelatin filled containers, which were then subjected to contact shots. This was sufficient to generate visible staining inside the firearm barrels. In order to reveal the distribution of blood inside the target model, a radiocontrast agent (barium sulfate) was added to the liquid mixture. This so-called "triple contrast method" allowed a detection of the traces using computed tomography (CT) [6]. Cutting the gelatin cores of the target models perpendicularly to the bullet path could only demonstrate the cracks in the gelatin left by the expansion of the temporary cavity, whereas the dynamic interaction of

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s12024-018-9971-0) contains supplementary material, which is available to authorized users.

✉ Christian Schyma
christian.schyma@irm.unibe.ch

[1] Institute of Forensic Medicine, University of Bern, Bühlstrasse 20, CH-3012 Bern, Switzerland

[2] Criminal Investigation Service of the Cantonal Police Department of Bern, Nordring 30, 3013 Bern, Switzerland

muzzle gases and the projectile with the target medium remained invisible.

As a consequence, the head model had to be re-designed so as to allow observation of the dynamic processes inside the target model using a high-speed camera. The development of a suitable target model, the 12 cm reference cube, was published recently [7]. From a wound ballistics point of view, the influence of the supporting base of such a small target model had to be considered. When the gelatin block is placed directly on a table, the table forms a rigid counterfort, preventing downwards expansion. In contrast, a gelatin block sustained by a sponge can expand in all directions. As we have shown recently for distant shots, the counterfort effectively had an influence on the expansion of the temporary cavity (TC) within the gelatin block provoked by expanding bullets. An elastic underlay allowed greater expansion and consecutively resulted in greater crack lengths in the gelatin, whereas when a rigid platform was used, an asymmetric distortion of the TC could be observed [8].

Hence, it was necessary to investigate whether the supporting base used under our gelatin cubes had an analogous importance in the context of contact shots when muzzle gases play a greater role than the energy transfer by the bullet. Furthermore, in this experimental setup, the influence of a counterfort on the staining observed inside the firearm barrels was of special interest.

Material and methods

Blood samples from informed, consenting, adult volunteers, were collected by venipuncture. The study design was approved by the ethics committee of the University Hospital Bonn. According to the triple contrast method [6], 2 ml of heparinized blood, 2 ml acrylic paint (CPM, Erkrath, Germany) and 1 ml barium sulfate-based radiocontrast agent Micropaque® (Guerbet, Brussels, Belgium) were mixed and sealed into thin 5×5 cm^2 foil bags. The bags were fixed by a gauze and glued on a synthetic absorbent kitchen wipe on top of which 10% gelatin solution was molded to create 12 cm large cubes as described previously [7].

Eighteen contact shots were performed with 4 in. barreled semi-automatic pistols: a Walther PP Sport cal. .22 LR, a Manurhin lic Walther PP cal. 7.65 Browning (.32 ACP) and a Smith & Wesson mod.5906 cal. 9 mm Luger. The following non-deforming ammunition was tested in the chosen pistols:

- .22 LR Mini-Mag (CCI, Lewiston, ID, USA), high velocity copper plated lead bullet, bullet weight 2.6 g, average velocity 263 m/s, average kinetic energy 90 J.
- .32 ACP full metal jacket bullet (Geco, Fürth, Germany), bullet weight 4.75 g, average velocity 325 m/s, average kinetic energy 251 J.
- 9 mm Luger full metal jacket bullet (Geco, Fürth, Germany), bullet weight 8 g, average velocity 320m/s, average kinetic energy 410 J.

With each firearm, six contact shots to gelatin cubes were performed. Three of the gelatin cubes were placed on a table and three were placed on a 5 cm high synthetic sponge, as described previously [8]. The shots were filmed using a SA-X2 high-speed camera with 40.000 fps, 10 µs exposure time (Photron Europe Ltd., West Wycombe, UK).

Video-endoscopy of the barrels was performed using a Hawkeye borescope (Gradient Lens Corporation, Rochester, New York) with a 0°-view optic [1]. Morphological assessment was performed by two independent investigators according to the grading system published previously [2, 7].

After each shot the guns were cleaned thoroughly with barrel cleaners of woolen felt and oil (WD 40), followed by an endoscopic control of the cleaning success.

After shooting, the target models (gelatin cubes) were documented as a whole by computed tomography [2, 6]. Thereafter, the gelatin cubes were cut into serial slices of 1 cm thickness, perpendicularly to the bullet path. Wound ballistic analysis was performed according to a previously published procedure [9].

Additionally, as proof of principle for the muzzle gas effect on the TC, the following experiment was conducted. At first, a contact shot to the target model was performed using a 9 mm blank cartridge and then a 9 mm full metal jacket bullet was fired from about half a meter distance in the pre-existing destruction zone. Another gelatin cube was first shot from a distance with the 9 mm projectile and subsequently a contact shot using a blank cartridge was placed into the preformed bullet path.

Results

Three semi-automatic pistols with 4 in. long barrels in different calibers were used to perform contact shots on the "reference cube". The differences concerning muzzle energy of the bullet and muzzle gas pressure were obvious. All bullets perforated the target model. Subsequent endoscopy of the firearm barrels revealed staining inside the barrel in each case. These traces were always of higher intensity in the anterior than in the posterior part of the barrel.

Walther PP Sport cal. .22 LR, .22 LR HV cartridge

Table 1 shows the staining results inside the barrels for six shots, differentiated for the anterior and the posterior half of the barrel in dependence on the sustaining underlay. In all six shots abundant staining was generated in the anterior part of the barrel. In the rear half of the barrel intensive staining was

Table 1 Staining in the anterior and posterior barrel part of the Walther .22 LR semi-automatic pistol

No.	Rigid counterfort (table)		No.	Elastic underlay (sponge)	
	Anterior part	Posterior part		Anterior part	Posterior part
1	+++	++	4	+++	++
2	+++	+++	5	+++	+++
3	+++	+++	6	+++	+++

observed up to the chamber (Online Resource1). A qualitative difference resulting from the underlay of the target model could not be discerned.

The analysis of the cross sections of the gelatin cubes showed similar profiles for all six shots regardless of the support. All parameters, the polygon area, the polygon perimeter [9], Fackler's wound profile (WP, the addition of the two longest cracks in each slice) and R_{max} (longest crack per slice) did not differ significantly for the rigid or elastic underlay. The maximum WP ranged between 40 and 47 mm for the rigid counterfort and between 40 and 46 mm for the elastic base. The maximum height of the temporary cavity (TC) observed in high-speed video reached 85 to 89 mm for the table and 88 to 93 mm for the sponge (Online Resource 2).

Manurhin lic. Walther PP cal. 7.65 Browning, .32 ACP FMJ bullet

The staining results of six shots are listed in Table 2, differentiated for both parts of the barrel in dependence on the sustaining base. In all six shots typical staining was generated in the anterior part of the barrel. In two shots no visible staining could be detected in the posterior part of the barrel. Three shots resulted in a staining of the chamber (Fig. 1). A qualitative difference resulting from the support of the target model was not observed.

Measurements of wound ballistic parameters in gelatin provided similar profiles for all six shots regardless of the sustaining base of the target model. Fig. 2 shows the profile of the averaged polygon area. The curves of R_{max}, Fackler's wound profile (WP), the polygon perimeter and the polygon area

Table 2 Staining in the anterior and posterior barrel part of the Manurhin 7.65 Browning semi-automatic pistol

No.	Rigid counterfort (table)		No.	Elastic underlay (sponge)	
	Anterior part	Posterior part		Anterior part	Posterior part
7	+++	+++	10	+++	++
8	+++	++	11	+++	+++
9	++	–	12	++	–

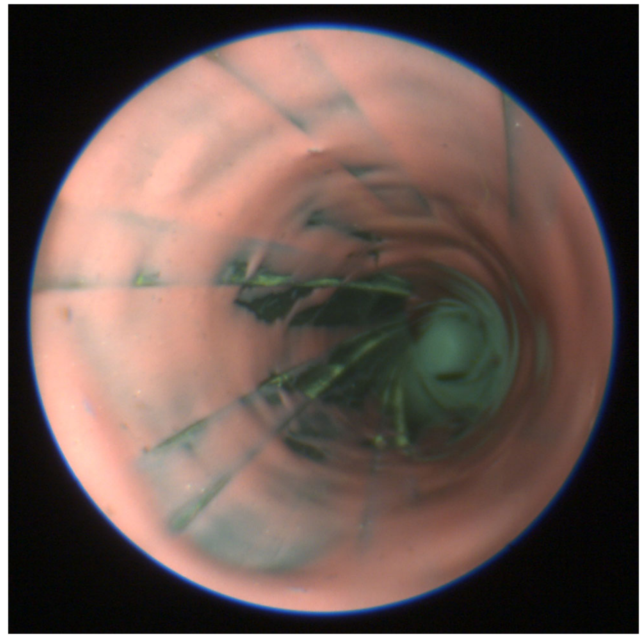

Fig. 1 Endoscopic view of the barrel of the .32 ACP pistol showing extended staining up to the posterior part

were practically identical for both underlays. The maximum R_{max} was 24, 29 and 25 mm for the rigid counterfort and 24, 25 and 24 mm for the elastic base. The meanR_{max} of the six shots in caliber .32 ACP (25 mm) was close to the mean R_{max} of those in caliber .22 LR HV (23 mm). The mean of maximal WP for the .32 ACP (48 mm) was slightly higher than the correspondent value for the .22 LR HV (43 mm). However, the difference between .22 LR and .32 ACP was more obvious in the high-speed video. In consequence, a first effect of the elastic underlay could be detected for cal. .32 ACP. The maximum height of the TC was higher (116 to 119 mm, average 117 mm) when the target model was placed on the sponge (Fig. 3) than in cubes placed on the table (107 to 111 mm, average 109 mm).

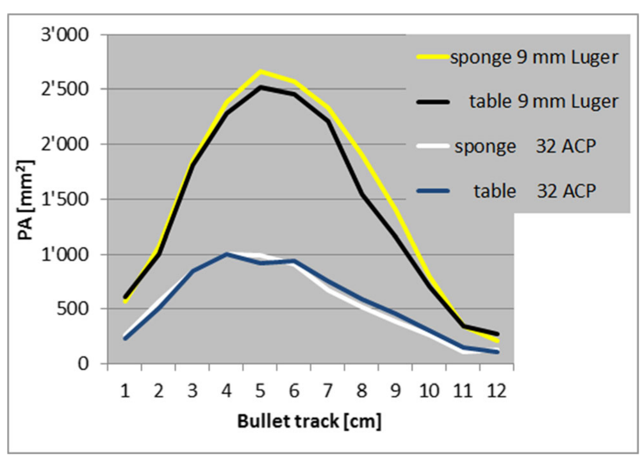

Fig. 2 Graph displaying the profile of the polygon area for .32 ACP and 9 mm Luger with differentiation of the underlay

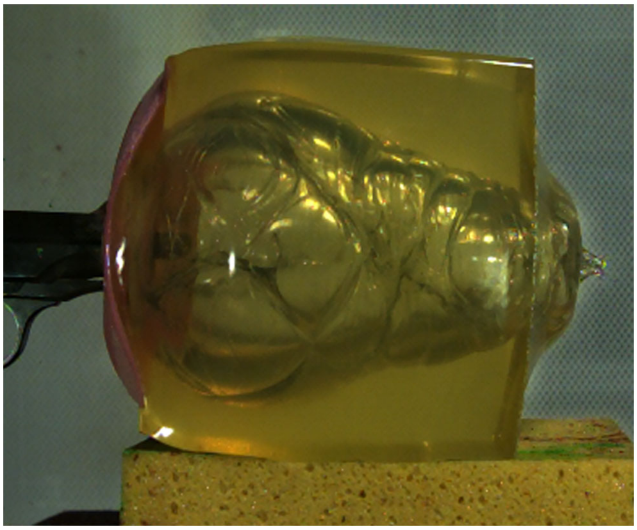

Fig. 3 Maximum TC obtained by a contact shot with the 7.65 mm Browning pistol using a .32 ACP FMJ bullet

Smith & Wesson mod. 5906 cal. 9 mm Luger, FMJ bullet

Table 3 shows the staining results of six shots, differentiated for the anterior and the posterior part of the barrel and the underlay used. In all six shots typical spray-like staining was generated along the barrel with decreasing intensity from the muzzle to the rear end. In four shots characteristic staining was observed up to the chamber (Online Resource 3). The sustaining base of the target model did not provoke qualitative difference in staining.

The wound ballistic parameters of the 9 mm Luger were clearly higher than those in the calibers .22 LR and .32 ACP. The behavior of these parameters is not consistent with regards to the different underlays. The polygon area (Fig. 2) achieves higher values for the elastic sponge. The curves of the polygon perimeter are identical for both underlays. The WP as well as the R_{max} were close together for both conditions, with smaller values for the sponge in the middle of the block and longer cracks at both ends, so that the elastic support seemed to equalize the formation of cracks. Hence the cumulated sum of all R_{max} was the same for table and sponge (Fig. 4). The analysis of high-speed video shows an averaged maximum height of the temporary cavity of 135 mm for the sponge and 130 mm for the table. In spite of this seemingly slight difference the flattening of the TC was clearly visible when the target model was placed on a rigid platform (Fig. 5).

Table 3 Staining in the anterior and posterior barrel part of the Smith & Wesson semi-automatic pistol cal. 9 mm Luger

No.	Rigid counterfort (table)		No.	Elastic underlay (sponge)	
	Anterior part	Posterior part		Anterior part	Posterior part
13	++	+	16	+++	++
14	+++	++	17	++	+
15	+++	++	18	+++	++

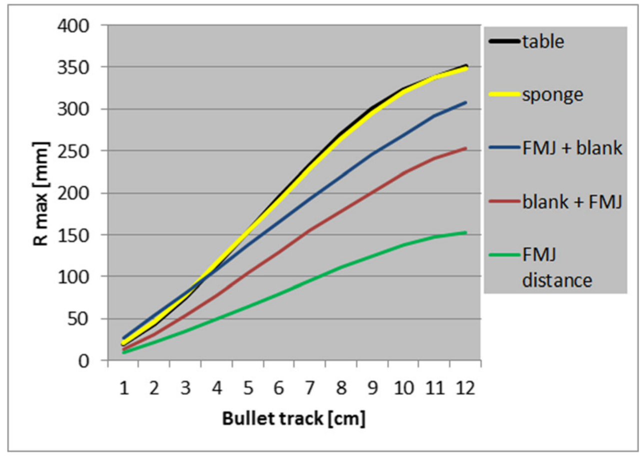

Fig. 4 Graph displaying the cumulated R_{max} (longest crack per slice) for 9 mm Luger FMJ. The curves above do not indicate an influence of the underlay. Best approximation of a contact shot is FMJ-blank (first perforation by the bullet, afterwards muzzle gas effect). The blank-FMJ (first blank cartridge, then bullet passing) shows more gelatin disruption than a simple shot from distance

Development of the temporary cavity when bullet and muzzle gas pressure are separated

Six experiments were performed to visualize the influence of the muzzle gas pressure on the distortion of the TC. Three target models were first subjected to contact shots using a 9 mm blank cartridge and then perforated by a 9 mm FMJ bullet from distance. Three other gelatin cubes were first perforated by a 9 mm FMJ bullet and subsequently sustained a contact shot using a 9 mm blank cartridge.

The analysis of the high-speed video records revealed an obvious difference of the TC's form. Only the series where the gelatin was first perforated and the muzzle gas pressure was applied subsequently showed a similar form of the TC to that

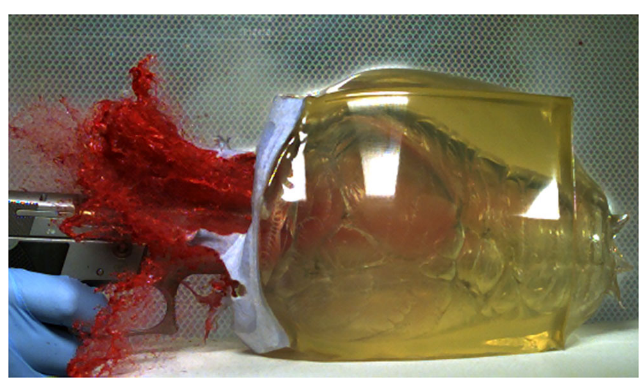

Fig. 5 Maximum TC after contact shot using a 9 mm Luger FMJ cartridge. The gelatin cube is placed on the table which provokes a flattening of the inferior margin of the TC

caused by contact shots using actual ammunition (Fig. 6a). A maximum height of 117 mm of the TC could be observed in high-speed video. This optical impression could be confirmed by cross sectional analysis of the gelatin blocks. In absolute values, the resulting destruction parameters ranged in the dimension of the 7.65 Browning. Fig. 4 shows the cumulated R_{max} of these experimental shots in comparison with the contact shots using actual 9 mm Luger ammunition.

The inverse experiment (first muzzle gas and then bullet) generated a tubular shaped TC (Fig. 6b) which was slightly wider (average 74 mm) than the ordinary tubular TC when a 9 mm bullet fired from distance passed through the gelatin cube (average 64 mm). This is confirmed by the increased cumulated R_{max} in comparison with a shot from distance which is given as a reference in Fig. 4.

Discussion

A systematic survey of suicides by firearms confirmed that gun barrels were stained by biological traces, especially after gunshots to the head with muzzle contact [3, 10], as previously described by Brüning and Wiethold [11]. In many cases, PCR of swabs gathered from the remains inside the barrel allowed for DNA typing and identification of the victim. Although this molecular genetic approach is successful in most cases, the heterogeneity of morphological findings inside the barrel could not be explained. This issue had been addressed in analogous manner with regard to the presence or absence of backspatter [e.g. 12–14] which can also be valuable evidence in shooting cases.

Funded by the Swiss National Science Foundation, a systematic experimental approach has been started in order to investigate how traces inside firearm barrels are formed. For this purpose a ballistic target model, the reference cube, has been developed as an experimental substitute for a head [7]. The front of this 12 cm gelatin cube is covered by an absorbent kitchen wipe, beneath which a thin foil bag containing acrylic paint, radiocontrast agent, and human blood [6] is mounted. The advantage of the transparent gelatin block [7, 15, 16] in comparison to silicone coated box models [2, 17] is the possibility of recording processes inside the target model using high-speed video. However, reducing the target cube to 12 cm in size (1.7 kg, simulating the intracranial mass of tissue and liquid) resulted in a different problem. To allow for unconstrained expansion of the temporary cavity (TC) an elastic underlay was required, as was demonstrated for shots from distance using expanding bullets [8]. Although we have used non-deforming bullets to generate staining in firearm barrels so far [2], the necessity of an elastic support of the reference cube had to be investigated, especially because muzzle gases increased the size of the TC in contact shots. This issue had not been addressed previously when investigating contact shots because the gelatin blocks that are usually used measure 25 cm × 25 cm × 40 cm which allows the large TC caused by muzzle gases to be demonstrated without restriction [15, 16].

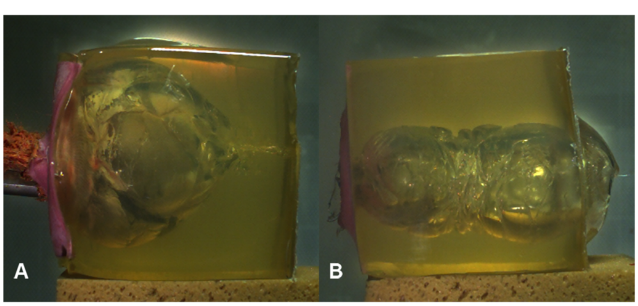

Fig. 6 Separation of bullet and muzzle gas effect. **a**: The 9 mm blank cartridge is fired after previous perforation by a 9 mm FMJ bullet. **b**: inverse order (first blank, then bullet)

Three current, semi-automatic pistols, in forensically relevant calibers, were used to perform contact shots to reference cubes with and without an elastic support. Staining, verified by endoscopy of the barrels, did not vary between gelatin cubes supported by a rigid counterfort or an elastic underlay. Additionally, cross-sectional analysis of gelatin slices did not reveal any significant differences concerning the remains of the TC, especially the crack length. The elastic sponge seemed to have a slightly equalizing effect on the differences between shorter cracks at the ends of the block and the longer ones in the middle. To verify this impression a much greater number of shots would be necessary, though when investigating the staining present inside firearm barrels after contact shots this might be a secondary consideration.

However, high-speed video documented that the expansion of the TC was bigger for all calibers when the gelatin cube was placed on a sponge. In particular, the shots from the 9 mm Luger showed a huge TC exceeding the dimension of the reference cube. Accordingly, when the target model was placed on the rigid table, the inferior margin of the TC was flattened. Curiously, this unchanging observation in the dynamic evolution of the TC did not achieve corresponding measurements in gelatin cross-sections. As opposed to this, deforming bullets have caused clearly longer gelatin crack lengths if the target model has been placed on an elastic underlay while the TC has shown comparable sizes.

To verify this discrepancy, a series of three shots to the reference cube was added to our protocol, in which we artificially separated the bullet path from the muzzle gas pressure. Indeed, only if the bullet passed through the target model first - fired from distance without muzzle gas effect - and a blank cartridge was subsequently fired into the bullet path as a contact shot, a qualitatively comparable TC was observed. Cross-sections of the gelatin showed a profile which was pronounced at the entry side, but stayed below a contact shot using actual 9 mm ammunition. The weaker result cannot be explained by the powder load of the 9 mm Luger blank cartridge (0.36 g) which is even greater than that of the 9 mm Luger FMJ cartridge (0.26 g). However, it could be possible that a loss of muzzle gas occurred, since the front of the block had been “injured” by the initial shot. The muzzle gas volume ballooned the lacerated gelatin and caused more and longer cracks than the simple energy transfer by a non-deforming bullet. The stretching effect of the gases could be of a different mechanical quality than the radial displacement by energy transfer although the TC in high-speed video looked similar.

In reverse order (first blank shot, then bullet) the TC was always different from contact shots. The gelatin slices as well as high-speed video showed the characteristics of a shot from distance and exhibited a slightly higher disruption.

This experiment suggests two aspects of contact shots:

- muzzle gas pressure is mainly acting after the projectile has passed
- blowing up the pre-existing cracks left by the projectile does not cause high crack lengths, as could be expected by the extension of the TC in high-speed video

Conclusion

In contact shots, the staining pattern inside firearm barrels was not affected by the sustaining underlay of the reference cube. No significant differences in the staining characteristic could be observed, although the temporary cavity of the .22 LR, the .32 ACP and the 9 mm Luger were different in size and in part distorted by a rigid counterfort of the target model. In consequence, future research should investigate the actual role of the temporary cavity on staining inside gun barrels.

Key points

1. Contact shots to reference cubes (12 cm large gelatin cubes doped with triple contrast mixture) placed on a rigid or an elastic underlay were performed using current pistols and non-deforming bullets, which always generated characteristic staining inside the barrels.
2. The nature of the staining was uninfluenced by the caliber used (.22 LR, .32 ACP, 9 mm Luger) and the support of the target model.
3. High-speed video revealed a distortion of the temporary cavity for 9 mm Luger contact shots as consequence of a rigid counterfort.
4. Cross-sectional analysis of the gelatin did not show significant differences in wound ballistic destruction parameters, especially crack lengths, for either rigid counterfort or elastic base of the target model.
5. High-speed video suggests that muzzle gas is blowing up the temporary cavity previously generated by the projectile.

Acknowledgments The expert technical assistance of Nicole Schwendener (Bern) is gratefully acknowledged.

Funding This research work was funded by the SNF (Swiss National Science Foundation, project 310030E-147628 / 1).

Compliance with ethical standards

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

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

References

1. Schyma C, Brünig J, Madea B, Jackowski C. Die Endoskopie des Waffenlaufes. Rechtsmedizin. 2016;26:224–9.
2. Schyma C, Bauer K, Brünig J, Courts C, Madea B. Staining in firearm barrels after experimental contact shots. Forensic Sci Int. 2017;273:64–70.
3. Schyma C, Madea B, Courts C. Persistence of biological traces in gun barrels after fatal contact shots. Forensic Sci Int Genet. 2013;7:22–7.
4. Grabmüller M, Schyma C, Euteneuer J, Madea B, Courts C. Simultaneous analysis of nuclear and mitochondrial DNA, mRNA and miRNA from backspatter from inside parts of firearms generated by shots at "triple contrast" doped ballistic models. Forensic Sci Med Pathol. 2015;11:365–75.
5. Courts C, Madea B, Schyma C. Persistence of biological traces in gun barrels – an approach to an experimental model. Int J Legal Med. 2012;126:391–7.
6. Schyma C, Lux C, Madea B, Courts C. The 'triple contrast' method in experimental wound ballistics and backspatter analysis. Int J Legal Med. 2015;129:1027–33.
7. Schyma C, Bauer K, Brünig J. The reference cube: a new ballistic model to generate staining in firearm barrels. Forensic Sci Med Pathol. 2017;13:188–95.
8. Schyma C, Herr N, Brünig J, Brenčičová E, Müller R. The influence of the counterfort while ballistic testing using gelatine blocks. Int J Legal Med. 2017;131:1325–32.
9. Schyma C, Madea B. Evaluation of the temporary cavity in ordnance gelatine. Forensic Sci Int. 2012;214:82–7.
10. Regneri W. Diagnostik bei Suizid mit Schusswaffen. Endoskopie von Waffenläufen und DNA-Analyse als komplementäre Methoden. Dissertation, Universität des Saarlandes, Homburg. 2006.
11. Brüning A, Wiethold F. Die Untersuchung und Beurteilung von Selbstmörderschusswaffen. Dtsch Z Gerichtl Med. 1934;23:71–82.
12. Betz P, Peschel O, Stiefel D, Eisenmenger W. Frequency of blood spatters on the shooting hand and of conjunctival petechiae following suicidal gunshots wounds to the head. Forensic Sci Int. 1995;76:47–53.

13. Karger B, Nüsse R, Schroeder G, Wüstenbecker S, Brinkmann B. Backspatter from experimental close-range shots to the head. I. Macrobackspatter. Int J Legal Med. 1996;109:66–74.
14. Davidson PL, Taylor MC, Wilson SJ, Walsh KA, Kieser JA. Physical components of soft-tissue ballistic wounding and their involvement in the generation of blood backspatter. J Forensic Sci. 2012;57:1339–42.
15. Kneubuehl BP. Simulants. In: Kneubuehl BP, Coupland RM, Rothschild MA, Thali MJ, editors. Wound ballistics: basics and applications. Berlin: Springer; 2011. p. 136–51.
16. GroßePerdekamp M, Glardon M, Kneubuehl BP, Bielefeld L, Nadjem H, Pollak S, et al. Fatal contact shot to the chest caused by the gas jet from a muzzle-loading pistol discharging only black powder and no bullet: case study and experimental simulation of the wounding effect. Int J Legal Med. 2015;129:125–31.
17. Schyma C, Bauer K, Brünig J, Schwendener N, Müller R. Visualization of the powder pocket and its influence on staining in firearm barrels in experimental contact shots. Int J Legal Med. 2017;131:167–72.