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ORIGINAL ARTICLE

Rearward movement of the slide in semi-automatic pistols: a factor potentially influencing the configuration of muzzle imprint marks in contact shots

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Abstract

A muzzle imprint mark is a highly diagnostic finding, which indicates a contact shot. In many cases, it also provides additional information on the type of the weapon used and on the way in which it was held at the time of firing. In semi-automatic pistols, some constructional elements constituting the muzzle plane move to the rear together with the slide, which may prevent them from causing a corresponding imprint close to the bullet entrance hole. The present study comprises 30 consecutive autopsy cases of fatal contact shots to the head inflicted with semi-automatic pistols. The imprint marks accompanying the entrance wounds were compared with the muzzle ends of the respective weapons both before and after retracting the slide. It turned out that in a considerable number of cases (3 out of 30), the retractable parts were not depicted or only to a minor degree as components of the imprint mark. In order to validate the presumed correlation, experimental shots were fired to composite models using pistols in which the movable and the stationary parts forming the muzzle plane were dyed with different paints. Thus, it could be demonstrated that the muzzle imprint preferentially mirrors the front sides of the stationary parts such as the barrel end, the recoil guide, and the gun housing. Immediately after discharge, the slide and the ballooning skin of the bullet entrance site move in the same direction. The stationary parts of the weapon block the expansion of the skin bulging towards the muzzle, so that the skin gets firmly pressed against them. The dynamic interaction between the gun and the entrance region resulting in a characteristic imprint mark could be visualized by the use of a high-speed motion camera recording test shots to different composite models.

Keywords Contact shot · Muzzle imprint mark · Semi-automatic pistols · Slide · Barrel marking · Recoil spring guide · Composite model

Introduction

Muzzle imprint marks are counted among the characteristics of contact shots just as soot deposition in the depth of the entrance wound ("pocket") together with bright-red tissue discoloration (due to the formation of carboxyhemoglobin) and stellate tears radiating from the bullet hole in the skin [1, 2]. Moreover, the muzzle imprint may indicate the type of the weapon and how the gun was held at the time of discharge [3–10]. From a traumatological point of view, the imprint mark can be considered as a patterned pressure abrasion and/or intracutaneous bruise [11] reflecting constructional elements located in the muzzle plane (or just behind).

It is commonly accepted that muzzle imprint marks in contact shots are caused by the high-pressure combustion gases entering the bullet entrance hole and expanding under the skin of the entrance site which bulges out and is pressed against the weapon's muzzle end [3, 4, 6, 7, 10, 12–15]. In principle, this mechanism applies to all kinds of firearms including pistols, revolvers, blank cartridge guns [16], rifles, and shotguns. However, in semi-automatic pistols, the question arises whether movable parts of a weapon's muzzle end (in concrete terms, the slide and constructional elements connected to it) are imprinted on the skin in the same way as the contours of

Dedicated to Prof. Gunther Geserick on the occasion of his 80th birthday.

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the barrel. Surprisingly, to the best of our knowledge, the literature dealing with gunshot injuries does not contain any systematic study on this topic. Almost all relevant monographs and articles are limited to general statements when describing the muzzle imprint mark. Some authors mention patterned marks which properly mirror individual components of the weapon, but do not explain why adjacent parts also located in the muzzle plane are not depicted.

Materials and methods

The present study includes 30 consecutive fatalities from contact shots to the head fired from semi-automatic pistols. The material comprises 30 victims (26 males and 4 females). Twenty-eight cases were suicides and the others homicides. The entrance wounds were located in the following head regions: right temple (21), left temple (1), forehead (2), submental region (4), and occipital region (2). Intraoral shots were left out of consideration. The pistols' calibers ranged from .22 Long Rifle to .45 ACP. There was no pre-selection of the weapons according to manufacturer, date of production, construction characteristics, models, or kind of ammunition. None of the pistols was equipped with a silencer or other device attached to the muzzle.

First, all corpses underwent X-ray examination of the head. After collection of evidence (especially gunshot residues), blood adhering to the skin around the gunshot entrance hole was carefully removed. If there were epidermal lesions not dried up yet, the abraded skin was exposed to air until it assumed a brownish discoloration due to parching. If necessary, reconstructive measures were performed prior to assessment (e.g., approximation of gaping tears by stitching them up [17]). Subsequently, photographs were taken showing the wound findings together with a scale. In addition, the appearance of each muzzle imprint mark was directly compared with the front end of the pistol used, both with the slide closed and open (locked in place by the slide stop). So, it could easily be determined whether the imprint only corresponded to the stationary parts or also to the recoiling elements.

In two exemplary cases, the front faces of the weapon parts constituting the muzzle plane were marked with different acrylic linoprint colors (aqua-Linoldruck Schmincke®, Erkrath, Germany). In both cases, the slide was colored black and the anterior edges of the housing frame red. In one of the weapons, also the recoil spring guide was dyed red, and in the other, the barrel end. Five test shots were fired from a pistol SIG P220 and 9-mm Luger (ammunition 9-mm Parabellum) and five from a pistol Česká zbrojovka, mod. 50, 7.65-mm Browning (ammunition 7.65-mm Geco) pre-treated in the above-mentioned manner. In order to prevent any transfer of color by mere contact before shooting, a firing distance of 2 mm was chosen (near-contact). A hard rubber mat (50 × 50 × 2.5, etm®) covered with a bright wax cloth was used as target. Directly behind the hard rubber mat there was a bullet trap.

Four experimental contact shots were fired to a skin-skull model composed of a polyurethane sphere (o. d. 19 cm, 5 mm thick) coated with a silicon scalp in two cases and with pig skin in the other two. The weapon used was a pistol SIG P210 (9-mm Luger). With the same weapon, two shots each were fired to compound models consisting of gelatine blocks (10% ballistic gelatine type III, 25 × 25 × 40 cm) and artificial skin (5-mm Dragon Skin from Synbone®) as well as to gelatine blocks covered with pig skin. To simulate a bony support a polyurethane mat (6-mm Synbone® Plate) was placed between the pig skin or the artificial skin and the gelatine block. The test shots to the models were video-documented by means of a high-speed motion camera (Motion X3® 1000 fps.).

Results

The total of 30 contact shots included 23 entrance wounds showing clearly discernible muzzle imprint marks, which presented as patterned abrasions and/or intracutaneous bruises. In three out of these cases, the imprints did not depict all constructional components located in the muzzle plane. These "partial" muzzle imprints reproduced only or mostly stationary pieces of the pistol's front side such as the barrel, the recoil spring guide, and the front end of the housing frame (Figs. 1, 2, and 3).

The shots performed after color marking produced similar patterns of staining corresponding to the (incomplete) muzzle imprint marks of the respective weapons (Figs. 1d and 2d).

The high-speed video documentation of contact shots fired to skin-skull models and the other composite models confirmed that both the silicon scalp and the pig skin bulged towards the muzzle, which was engulfed by the ballooning skin. At the same time, the recoiling slide and the parts attached to it moved backward and thus there was no hard contact to cause a pressure abrasion (Fig. 4). The muzzle marks on the pig skin also did not reflect the mobile and the stationary components of the muzzle to the same extent.

Discussion

The first reports on patterned imprint marks adjacent to the entrance holes of contact shots date back to the late nineteenth century. The famous atlas of Eduard v. Hofmann [18] contains the photographic representation of a contact entrance wound in the right temple region of a suicide. The shot was inflicted with a double-barreled pistol involving a ring-shaped marking from the non-firing barrel. Similar findings have been repeatedly reported in connection with contact shots from multi-barreled weapons as used for hunting [3, 17, 19–25].

Fig. 1 **a** Contact gunshot wound to the right temporal region accompanied by an imprint mark from the recoil spring guide. For purposes of comparison, the inserted photo shows the muzzle plane of the weapon used. **b** Lateral view of the pistol SIG P220 (9-mm Luger) with the slide closed and open. **c** Muzzle end (frontal and angled view). The front of the slide and the barrel end are colored black, whereas the recoil spring guide and the anterior edge of the housing frame are colored red. **d** Near-contact test shots to a hard rubber mat covered with a wax cloth produced intense red imprints from the recoil spring guide. The black imprint was pronounced only around the bullet entrance hole

Patterned imprints in the vicinity of the gunshot entrance hole are not only caused by a weapon's muzzle in the narrow sense, i.e., the "mouth" of a firearm, but also by other constructional elements located in the muzzle plane or just behind (front sight, its socket and any guard, the housing frame, any barrel and recoil spring guide bushings as well as the front end of the guide rod itself). In some revolvers, the ejector rod head is situated not far behind the muzzle so that it can also produce an imprint mark. Apart from the abovementioned weapon components, there may be additional constituents contributing to the muzzle imprint such as the folded shoulder stocks in submachine guns [26] or ramrods in muzzleloaders [27]. A case impact mark located close to a gunshot entrance wound can simulate a component of the muzzle imprint [28].

It is a matter of common knowledge that the imprint marks in contact shots from semi-automatic pistols are multiform and therefore particularly informative as to the type of weapon used. This is a result of the great number of construction variants involving different shapes of the pistol's muzzle end. The multitude of variants is related to the mechanism ensuring the extraction and ejection of the empty case and the reloading of a fresh cartridge so that the next round can be fired. Semi-automatic pistols use the forces generated by the combustion gases. The two most common methods of operation are the following: (1) the blowback system in which the unlocked slide is pushed to the rear (destined for low-powered cartridges) and (2) the locked breech action where the breechblock initially is locked into the barrel so that slide and barrel are pushed backwards together for a certain distance until the locking mechanism is disengaged; the locked breech design is also suitable for higher-powered pistol cartridges [29, 30].

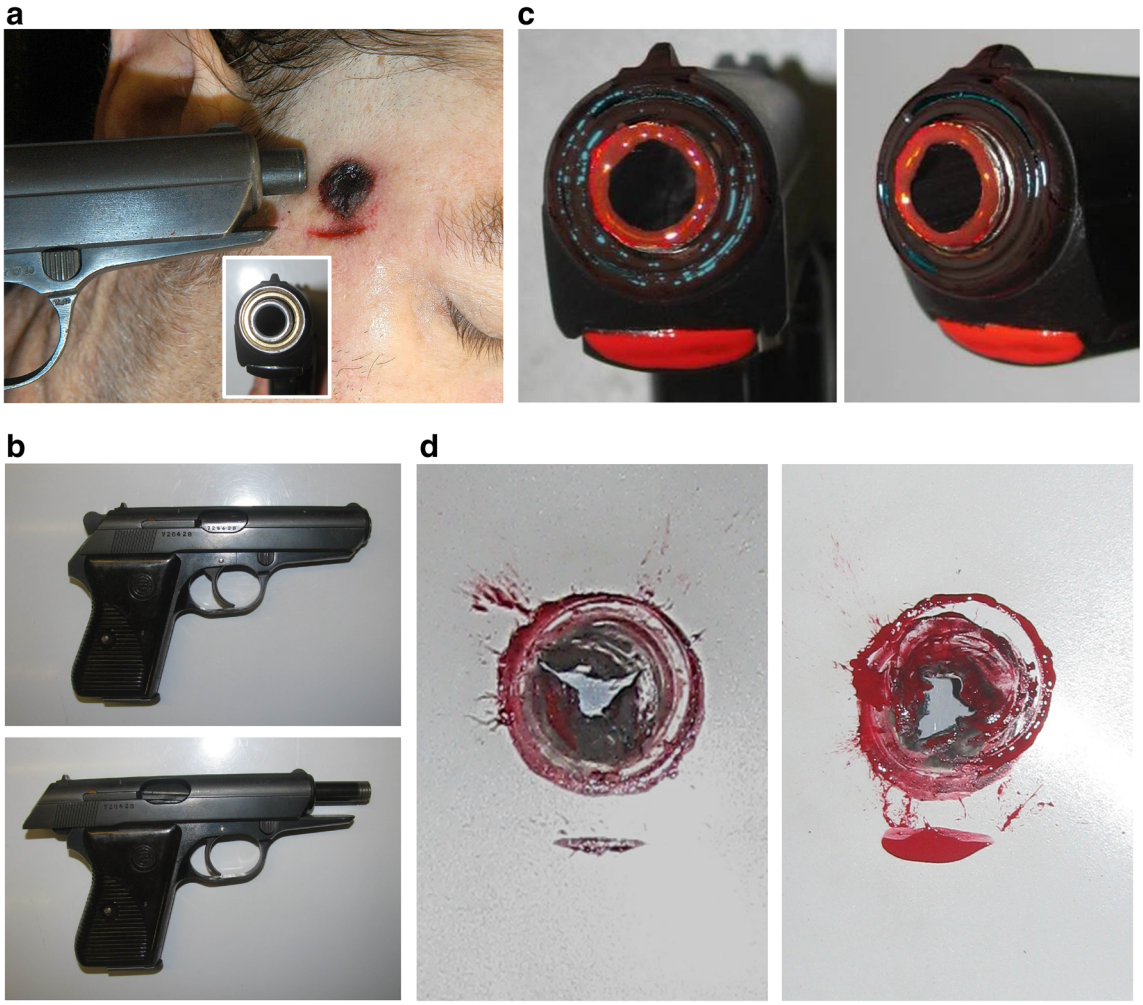

Fig. 2 **a** Contact gunshot wound to the right temporal region accompanied by an imprint mark from the barrel end as well as from the anterior edge of the housing frame. For purposes of comparison, the pistol with its partly retracted slide is placed next to the bullet entrance site. The inserted photo shows the muzzle plane. **b** Lateral view of the pistol Česká zbrojovka, mod. 50 (7.65-mm Brown.) with the slide closed and open. **c** Muzzle end (frontal and angled view). The front of the slide is colored black, whereas the barrel and the anterior edge of the housing frame are colored red. **d** Near-contact test shots produced intense red imprints from the barrel and housing

In semi-automatic pistols, the slide and all parts firmly attached to it already begin to recoil when the bullet has left the barrel. This means that the movable parts of the muzzle plane are retracted whereas the stationary components remain in the same position (not taking into account the backward movement of the gun as a whole). As a consequence, the interaction between the skin of the bullet entrance site and the pistol being in contact with it should actually be confined to the stationary components or should at least be more pronounced compared to the retracting slide. Dependent on the relative position of the recoiling breech in relation to the skin bulging out against the muzzle, the imprint mark may be "incomplete" due to the recoil mechanism.

As we already pointed out in our historical review [31], Werkgartner [3, 4] was the first who systematically analyzed contact entrance wounds from semi-automatic pistols with regard to accompanying imprint marks corresponding with the muzzle shape. He correctly ascribed this phenomenon to the high-pressure combustion gases, which enter the body together with the bullet causing backward ballooning of the skin with consecutive imprint of the muzzle. In the period between the world wars, some other mechanisms were (erroneously) considered to have an effect on the formation of muzzle marks (for details see [5]). Several authors held the opinion that the secondary forward motion of the slide (after extraction and ejection of the fired case) is—at least partly—responsible for the muzzle-skin interaction [3, 6, 13]. Others considered it possible that a muscular counter-reaction to the weapon's recoil might force the muzzle towards the bullet entrance site [6, 32]. Another concept started from the (wrong) assumption that the penetrating bullet indents the skin in a funnel-like manner followed by circular abrasion from the external edge of the barrel's end [3, 13]. A suction effect originating from the barrel inside after escape of the

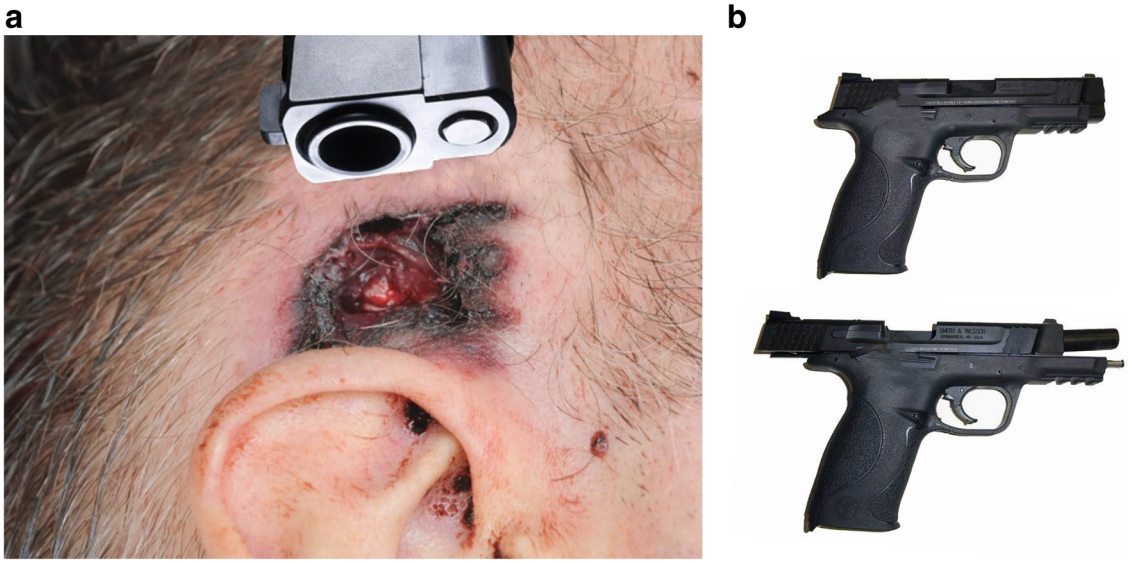

Fig. 3 **a** Contact shot to the head (bullet entrance site above the right auricle). The imprint mark from the recoil spring guide is particularly pronounced just as some contours of the muzzle plane. **b** Lateral view of the pistol Smith & Wesson M&P 45 (.45 ACP) with the slide closed and open

combustion gases was as well suspected of causing the imprint mark [12, 33]. The mere fact of a firm contact between muzzle and the skin at the moment of discharge was also attributed for the creation of a muzzle imprint mark [32].

Fig. 4 **a** Image sequences of an experimental contact shot fired to a skin-skull model composed of a polyurethane sphere coated with pig skin. The weapon was a pistol SIG P210 (9-mm Luger). The skin of the entrance site shows its maximum expansion 4 ms after the shot was triggered. **b** Contact shot with a pistol SIG P210 to a compound model consisting of a gelatine block coated with pig skin. Retrograde bulging of the skin reached its maximum after 4.7 ms. **c** Contact shot to a gelatine block coated with pig skin and a polyurethane map lying underneath (to simulate a bony support). Maximum expansion of the bloated skin after 5.7 ms.

The analysis of our study material confirmed the high diagnostic relevance of muzzle marks in contact shots from semi-automatic pistols. The vast majority of entrance wounds (23 out of 30) were associated with more or less patterned excoriations and/or intracutaneous bruises. The overall frequency of muzzle imprint marks amounted to 77%, which is quite comparable with the proportion reported by Werkgartner [3] in 1924 (three out of four). In some pistols such as the famous Parabellum (in the US commonly known just as "Luger"), the front end of the breech is located far behind the muzzle even before recoil. In such cases, the slide cannot be involved in the imprint, and the skin mark only reflects the barrel edge and possibly the front sight.

In the majority of cases (17 out of 23), the movable and the stationary elements sharing in the muzzle plane did not leave an imprint of equal intensity. Often it turned out that the recoil spring guide left the most prominent mark, which not uncommonly appears as a punched-out hole in the skin [3, 4, 6, 17, 34], cf. Fig. 1a. The relative position of the imprints caused by the barrel on the one hand and by the recoil spring guide on the other hand provides information about the way in which the weapon was held when the shot was fired. In pistols with an edged front end of the housing frame, this part frequently left a characteristic imprint mark being indicative of both the weapon type and any twisting of the grip [4, 17, 32]. The diagnostic relevance of imprints from edged housing parts was demonstrated as early as in the 1920s and 1930s of the last century [3, 4, 6]. In the presence of linear slits, these might be mistaken for stab wounds [6, 35].

Already in the first fundamental analysis by Werkgartner [3], the movable parts of semi-automatic pistols were linked with the occurrence of muzzle imprint marks. Surprisingly, only the secondary forward action induced by the recoil spring was taken into consideration as the causative mechanism. It was thought that the spring force exerted on the recoiled slide would push the weapon against the target and thus bring about a hard contact with the muzzle [3, 6, 13]. Later on, this hypothesis was rejected with reference to the temporal delay of the slide's forward motion taking place at a time when the imprint formation is already finished [12]. A further argument against the assumption of an impact due to the slide's anterograde movement after case ejection was rightly seen in the fact that imprint marks from contact shots can also be observed with guns not having a self-loading system (e.g., shotguns). Based on high-speed photo-documentation, Elbel [13] arrived at the conclusion "that the mechanism of movable weapon parts is immaterial regarding the formation of a gunshot entrance wound" (1958). Nevertheless, this statement requires an addendum insofar as the recoil-induced backward movement of the slide may prevent some muzzle parts from being imprinted on the skin.

Ever since muzzle imprints have been described, particular attention was paid to the shape of the skin mark and its relationship to the constructional elements of the gun. In 1935, Garsche [6] produced molds in Plasticine™ reflecting the muzzle plane of the weapon used in order to compare its contours with real skin marks. In 1944, Hausbrandt [12] performed test shots after staining the frontal aspects of the muzzle parts with different aniline dyes. In this way, certain segments of the color-coded imprint could be attributed to the respective structural components of the pistol. As to the size, i.e., the metric dimensions, an exact congruency of the muzzle and its imprint cannot be expected due to the dynamic interaction between the deformable skin and the rigid weapon parts, especially in entrance wounds with radiating tears. Hausbrandt [12] found out that apart from firm contact shots also near contact shots may be associated with patterned muzzle marks. Interestingly, he did not address the question whether movable parts leave less distinct imprints compared with stationary components. However, Hausbrandt concluded that both the movable and the stationary elements may cause skin marks, if the entrance region bulging out against the muzzle hits the respective weapon parts either simultaneously or in quick succession. Our own test shots using pistols with dyed front faces revealed that there may be distinct differences between movable and stationary parts with regard to the imprint intensity. This finding was in consistence with the (partial) muzzle marks in contact shots from corresponding weapons (cf. Fig. 3a).

High-speed photo-documentation of experimental contact shots is a valuable tool to study the motion sequences at the bullet entrance site [13, 14, 36–38]. On this basis, Elbel [13] deduced already in 1958 that the muzzle imprint is exclusively caused by the backward ballooning of the skin due to the subcutaneous expansion of the inrushing combustion gases. On the other hand it was found that other mechanisms discussed in this context (secondary forward motion of the slide, muscular counter-reaction to the pistol's recoil or suction effect from the barrel) do not contribute to the formation of muzzle imprints. In order to study the dynamic development of the muzzle imprint, contact shots were fired to a skin-skull-brain model [14] showing the temporal sequence of the weapon-target interaction.

In the present study, the video-documented test shots were fired to different composite models: (1) polyurethane spheres covered either with artificial or pig skin, (2) gelatine blocks with artificial or pig skin attached to the front side, and (3) a model composed of artificial or pig skin over a layer of polyurethane (simulating a bony support) and gelatine. In principle, our findings confirmed the knowledge as previously published in the relevant literature [14, 39]. Nevertheless, a stereotyped adaptation of experimental results to the wound morphology of a specific case seems inadmissible considering the great number of influencing factors in real-life conditions: weapon type, ammunition, firm/loose/near/angled contact, physical properties of the skin, presence/absence of a bony support, etc. Therefore, it is difficult to predict in an individual case how fast the breech will recoil in comparison to the retrograde bulging of the bullet entrance site.

In spite of the fact that both the recoiling elements and the ballooning skin move in the same direction, the starting points and the velocities may be different, not least dependent on the design of the breech-reloading action (blowback, delayed blow back, locked breech). Among the numerous variants, short recoil operation (barrel and bolt recoil together for a short distance only before they unlock and separate) as used in centerfire, semi-automatic pistols chambered for 9 × 19 mm Parabellum cartridges should be mentioned as an example. Anyway, it was demonstrated by our test shots that the recoiling slide can travel a considerable distance before the skin of the bullet entrance site bulges out against the muzzle. That implies that the skin is preferentially exposed to the stationary parts of the muzzle such as the barrel end and the recoil spring guide. In angled contact shots, the varying distance between the individual parts of the muzzle plane and the skin is another factor which may potentially cause an incomplete or asymmetric muzzle imprint mark.

Conclusions

- In semi-automatic pistols, the slide and other constructional parts connected with it perform a recoil-induced backward motion in relation to the stationary parts of the weapon (barrel, recoil spring guide, housing frame).
- In contact shots, this relative motion may implicate the formation of a partial muzzle imprint mark which exclusively or preferentially reflects the stationary parts.
- The configuration and orientation of the imprint components potentially provide indications of the weapon type and the way in which the weapon had been held at the moment of discharge.
- Experimental (near) contact shots using pistols with diversely colored muzzle components leave imprints resembling those in victims and showing which parts of the muzzle are depicted.
- High-speed photo-documentation of contact shots to composite models records the time-dependent interaction between the skin of the entrance site and the weapon's muzzle elements.

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