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CASE REPORT

Intersecting fractures of the skull and gunshot wounds. Case report and literature review

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Abstract When two fracture lines of a solid surface (ice, glass, eggshell, etc.) intersect, it is always possible to tell which one has been made first. Indeed pre-existing damage of the surface arrests all the fracture lines produced by subsequent impacts. This well-known principle (established by Puppe in 1903) has been largely used in glass fracture analysis, but can be applied also to the examination of skull fractures. It can help sequencing blunt force or gunshot injuries determining the direction of fire and differentiating entrance from exit wounds in the absence of specific distinguishing features (i.e., internal/external beveling of the skull or overlying skin indicators). In this context, we report the case of a 76-year-old man who shot himself in the mouth with a Walther PPK 7.65 handgun and highlight the utility of the application of both Puppe's Rule and Multislice Computed Tomography (MSCT) in the examination of gunshot wounds to the skull.

Keywords Gunshot wounds · Forensic · Skull fractures · Intersecting fractures of the skull · Sequence of fire · Puppe's rule · Entrance and exit wounds · Multislice Computed Tomography (MSCT)

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Introduction

Puppe's Rule, established by the German forensic pathologist Puppe in 1903 [1], states that when two or more fracture lines of the skull produced by different blunt forces intersect, it is possible to reconstruct the sequence of injuries [1–3].

The intact skull allows fracture lines to develop normally while the presence of bone damage causes the subsequent injuries to stop in the point of intersection with the previous wounds. In other words, the fracture lines produced by subsequent impacts are arrested at pre-existing fractures of the skull (Fig. 1) [2, 3].

No exception to this rule has been found in systematic investigation on skulls, glass, and eggs stricken with subsequent blows [4].

Although multiple gunshots cause an extensive and sometimes very complex pattern of fractures (hydrodynamic effect produced by the bullet transversing the temporal cavity of the brain) [5–8], in the majority of cases Puppe's rule can be successfully applied [3, 4, 9–13].

Indeed, by impacting the skull the bullet creates a bone deformation very similar to that produced by a blunt force instrument when medium or large caliber handguns are used [4, 7, 11–13].

Depending on the mass, velocity, direction, and site of impact of the bullet [3, 7, 9], gunshot wounds to the skull vault usually show two pattern of fractures: radial fractures originating from the point of impact and concentric fractures centered around the entrance or exit hole [3, 5, 8].

Generally specific features help distinguishing entrance from exit wounds: the former show a round or ovoid shape with internal beveling of the inner table, while the latter are larger, and more irregular and present an external beveling of the outer table [8, 14, 15].

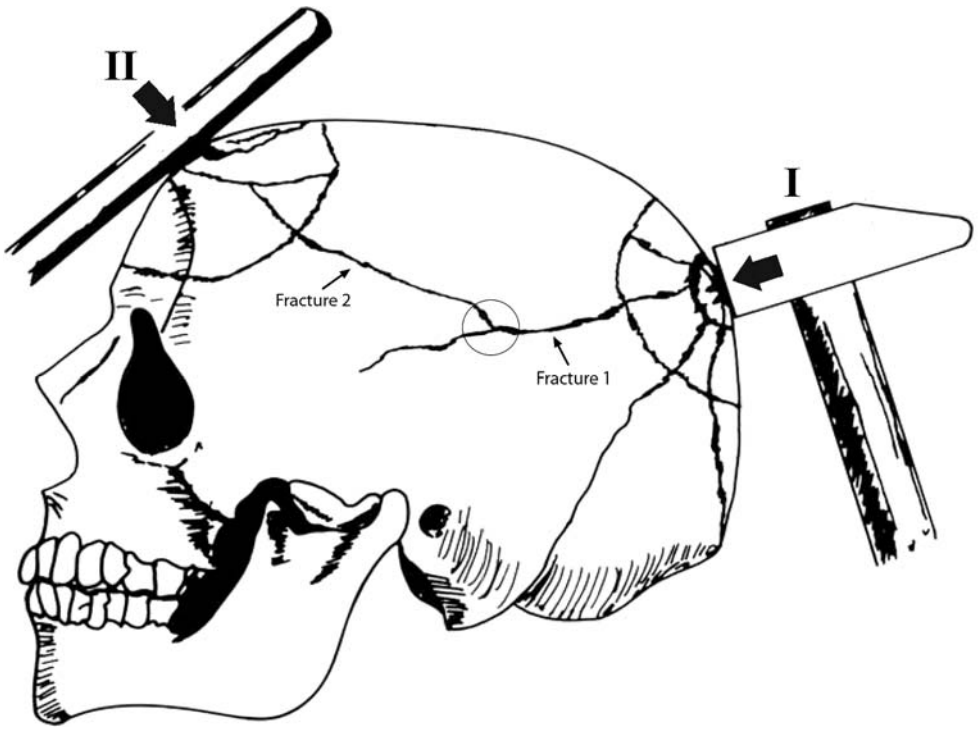

Fig. 1 Illustration of Puppe's rule, modified after Madea [6]. Two blunt force injuries to the skull with an intersecting fracture. A fracture line produced by the second impact is arrested at a pre-existing fracture line (black circle)

However, these characteristics can sometimes be absent or difficult to appreciate, and in these cases Puppe's rule can be a valid alternative tool in differentiating entrance from exit gunshot wounds to the skull vault.

Herein, we report the case of a 76-year-old man who shot himself in the mouth with a Walther Manurhin PPK 7.65 handgun (caliber 9 × 17 mm) and discuss the utility of the application of both Puppe's Rule and Multislice Computed Tomography (MSCT) in the investigation of shooting crimes.

During the last few decades, there have been great improvements in forensic radiology due to the introduction and optimization of sectional techniques (such as MSCT and magnetic resonance imaging) that have increased the ability of localizing the bullet, identifying the type of weapon used, and documenting the path of the bullet [16–18].

Case report

A 76-year-old man committed suicide shooting himself in the mouth with a Walther Manurhin PPK 7.65 pistol (Fig. 2a). Two months before he was found to be affected by a pancreatic carcinoma with systemic metastatization. During death scene investigation, police officers found him lying on his back with the pistol in the left hand and the left index still on the trigger.

Prior to autopsy a total body MSCT scan was performed. MSCT scanning was executed on an Mx 8000 Quad Diamond select unit (Philips Medical Systems, Andover, MA). In areas of forensic importance, axial MSCT was performed with 4 × 1.25 mm collimation. The duration of MSCT scanning in our case was approximately 15 min. By the use of an open-source workstation (OsiriX version 3.1) it has been possible to calculate two-dimensional sagittal and coronal reformations and three-dimensional reconstructions.

Major radiological findings were: a bone defect of the vault with external beveling of the outer table (Fig. 3a, b), an anterior pneumoencephalus (Fig. 3a), a fracture of the anterior cranial fossa (Fig. 3a), a complex pattern of fractures of the ethmoid bone with hemorrhagic filling of the ethmoid sinus (Fig. 3a), and a bone defect of the hard palate (Fig. 3a).

Orthogonal multi-planar reconstructions allowed us to estimate the direction of fire in both coronal and sagittal planes.

At forensic external examination, a stellate-shaped wound with large skin and soft tissue defects was present at the top of the vault (near the bregma). No margin of abrasion or gunshot residues were found.

The dorsum of both hands showed spray-like blood-stains, whereas the medial part of the right thumb showed two small fresh bruises (diameter 0.2 cm) (Fig. 2b). At oral inspection in the anterior third of the hard palate, a round tissue defect (2 cm in diameter) with a considerable deposit of gunshot residues was evident.

Autopsy revealed that the wound track had involved the left orbita and had entered the skull through the left

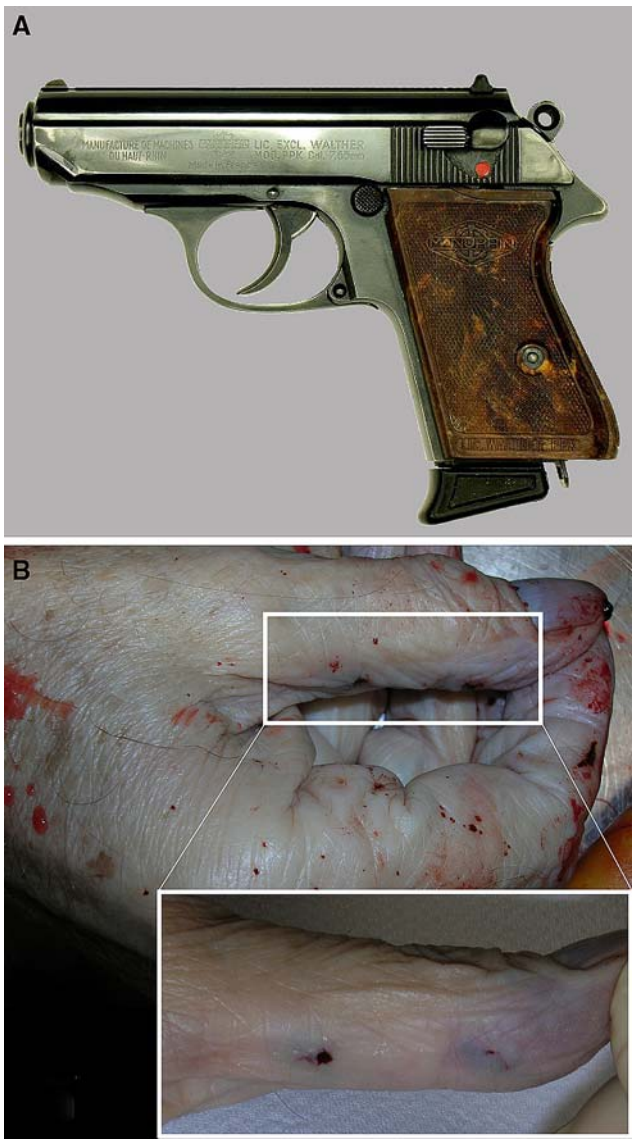

Fig. 2 **a** Picture of the weapon used by the victim, a Walther Manurhin PPK pistol. It is a blowback-operated semiautomatic pistol with an exposed hammer, a double-action trigger mechanism, a single-column magazine and a fixed barrel which also acts as the guide rod for the recoil spring. Caliber: 7.65 mm **b** Picture of the dorsum of the right hand with spray-like bloodstains; at a greater magnification two fresh bruises (diameter 0.2 cm) on the medial surface of the right thumb produced by the action of the pistol's slide during the firing cycle

anterior cranial fossa in a point located 2 cm far from the sella turcica and 1 cm far from the midline.

The examination of the base of the skull showed a complex maxillofacial pattern of fractures with fragmentation of the ethmoid bone and a transverse fracture line of the anterior cranial fossa. The transverse fracture (as a "hinge facture") radiated to the skull vault entering the left fronto-temporal bone and crossing the left parietal bone (Fig. 3c, d).

At the top of the vault (at 2 cm distance in front of the lambdoid suture) a round defect of the skull was found. At the inner table the hole measured 1.2 cm in diameter, while at the outer table it measured 2.3 cm; an external beveling of the outer table was present (Fig. 3a, b). Six radial fracture lines departed from the center of the hole, the deepest one directed through the parietal bone and arrested in the left parieto-occipital region by the fracture line ascending from the left fronto-temporal region (previously described and belonging to the entrance wound pattern) (Fig. 3c, d).

The wound canal involved the left frontal lobe of the brain with an oblique orientation (60° of inclination in the sagittal plane and about 10° of inclination in the frontal plane); fresh contusions surrounded the wound track for about 1 cm. Bilateral subdural and subarachnoid hemorrhages of the frontal lobes were present.

Other major autopsy findings were: a solid tumor of the head of the pancreas (6 × 3 cm) without lymphnodes involvement; a solitary subpleural metastasis (diameter 1 cm) localized at the inferior lobe of the right lung; two metastasis of the liver (diameter of 2 cm); a spleen enlargement; and a multivascular atherosclerosis.

Discussion

When two fracture lines of a solid surface (ice, glass, eggshell, etc.) intersect, it is possible to determine which one has been made first [1]. Indeed a pre-existing damage of the surface arrests all the fracture lines produced by subsequent impacts [1–4]. This well-known principle (established by Puppe in 1903) has been largely used in glass fracture analysis, but can be applied also to the examination of skull fractures (Fig. 1) [1–4, 10–13].

Madea et al. have described several cases of multiple gunshot wounds in which Puppe's rule allowed the pathologist to reconstruct the exact sequence of fire [3, 6, 10, 11]. Similarly Spitz and Fisher have correctly estimated the order of determination of two entrance holes into the head in close proximity analyzing the bone fractures [19]. On the other hand, Dixon has highlighted the importance of intersecting fracture pattern analysis in identifying the direction of fire [12].

Moreover, some Authors have discussed the applicability of Puppe's rule in recognizing exit gunshot injuries [3, 6, 12]. This could be particularly important when external beveling or overlying skin indicators are absent (decomposition of the body, animal or insect damage, incineration, etc.) or when external beveling is present also at the site of entry [20–24].

Linear fractures related to the entrance wound generally travel faster (450 m/s) [2] than the bullet which formed

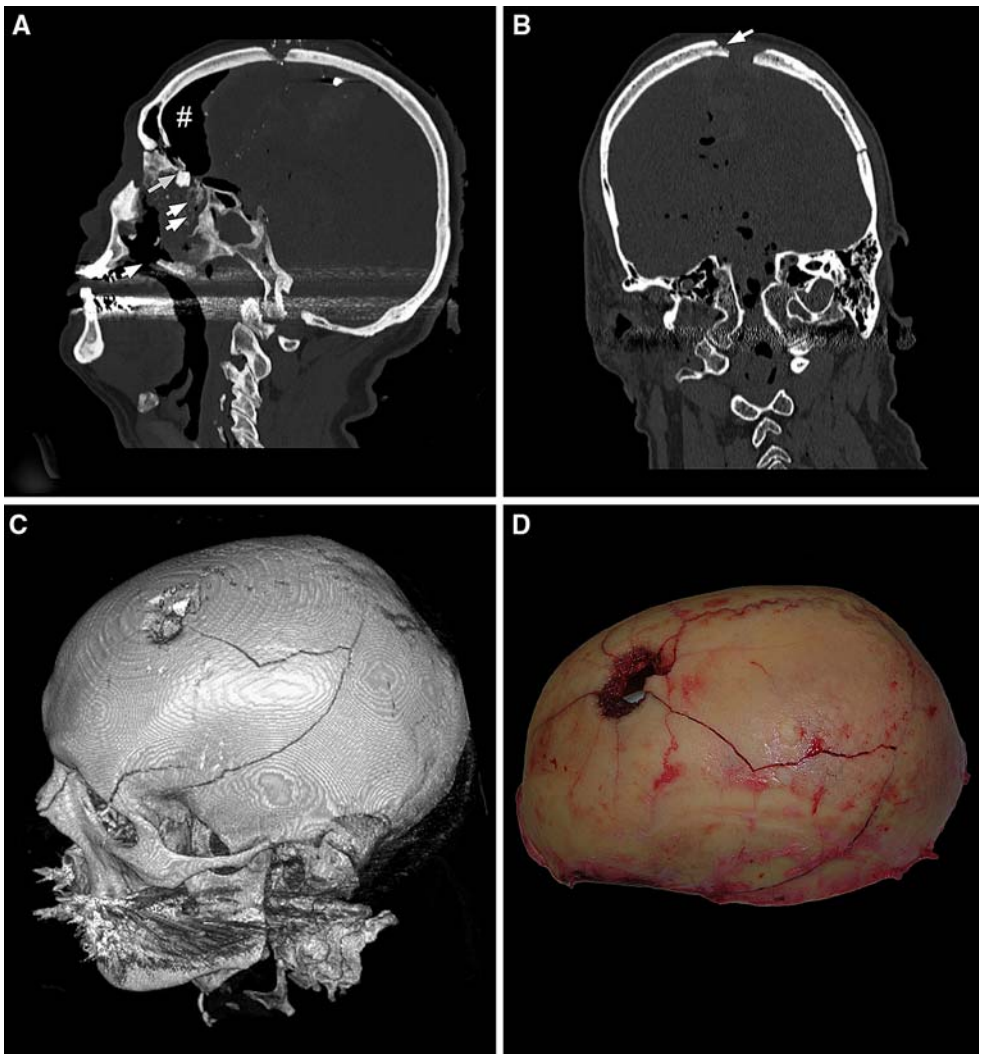

Fig. 3 **a** Multi-planar reconstruction (sagittal view). Damages caused by the entering bullet: bone defect of the hard palate (white arrow), complex pattern of fractures of the ethmoid bone with hemorrhagic filling of the ethmoid sinus (two white arrows), fracture of the base of the anterior cranial fossa (gray arrow), anterior pneumoencephalus (white symbol #); **b** Multi-planar reconstruction (frontal view). External beveling of the exit gunshot wound (white arrow). **c** 3D-CT reconstruction of the skull. Gunshot exit hole at the top of the vault with radiating fractures. Abrupt termination of a parietal fracture line belonging to the exit wound pattern at a pre-existing damage caused by the entering bullet (Puppe's rule). **d** Autopsy picture of the vault with the exit gunshot wound, the radiating fracture lines and the abrupt termination of the parietal fracture line

them; that is the reason why facture lines radiating from the exit hole are usually stopped by those belonging to the entrance hole pattern of fractures [3, 11, 12].

In the reported case, the abrupt termination of the left parietal fracture line (belonging to the exit wound pattern) at the pre-existing damage caused by the entering bullet (well documented by the 3D-CT reconstruction and by the autopsy pictures, Fig. 3c, d) is a good visual example of Puppe's principle and allowed us to differentiate between the entrance and the exit gunshot wound.

Even if the presence of gunshot residues in the mouth and the external beveling of the outer table at the top of the vault seen at autopsy left no doubt about the site of entrance of the bullet, CT scans enhanced the identification of the pattern of fractures of the ethmoid bone and of the hard palate.

Moreover, orthogonal multi-planar reconstructions (Fig. 3a, b), offering the possibility of a virtual dissection in varying planes without any anatomical alterations, gave a clear picture of the wound canal and allowed a better estimation of the direction of fire.

The advantages of MSCT in the postmortem investigation of gunshot wounds to the skull have already been repeatedly demonstrated [16–18, 25].

Our report confirms that one of the major advantages of CT scans lies in the possibility of reconstructing the processes and mechanisms of trauma. In particular, gunshot wound channels can be portrayed in a way that would not be possible in the course of a conventional, destructive autopsy [25].

In the case under investigation, MSCT identified a bone defect of the hard palate, a complex fracture of the ethmoid bone with hemorrhagic filling of the ethmoid sinus and a bone defect of the vault with external beveling (Fig. 3a, b).

These findings allowed a clear identification of the bullet path and gave a powerful forensic visualization of hardly accessible sites at autopsy (ethmoid bone and ethmoid sinus).

Nevertheless, MSCT scans could not allow a complete reconstruction of the event. Forensic autopsy, identifying two small bruises at the internal surface of the right thumb produced by the action of the pistol's slide during the firing cycle (Fig. 2b), gave additional information about the dynamics of the event showing that the victim grabbed the weapon with both hands while pulling the trigger with his left index.

The reported one is only an example of the limitations of the postmortem MSCT method, the most important of which are imposed by the absolute resolution of the systems, by the problematic documentation of superficial injuries (lack of definition and of color information), and by the difficult radiographic interpretation of comingling or crossing paths in subjects who have sustained multiple gunshot wounds.

At the present time, even if some of these weaknesses could be successfully compensated through the additional use of magnetic resonance imaging and surface scanners [26], we believe that postmortem MSCT should be considered a valid complementary tool and not a substitute for an autopsy.

Educational message

1. Puppe's rule states that when two or more fracture lines of the skull produced by different blunt forces intersect, it is possible to reconstruct the sequence of injuries.
2. This rule can be applied also to the examination of gunshot wounds enhancing the identification of the sequence and direction of fire.
3. Sometimes Puppe's principle can be an alternative tool in the differentiation between entrance and exit gunshot injuries, above all if external beveling or overlying skin indicators are absent.
4. MSCT offers the possibility of a virtual dissection in varying planes without any anatomical alterations giving a powerful visualization of hardly accessible sites at autopsy (ethmoid bone and ethmoid sinus in the reported case).
5. MSCT scans, with consecutive 2D and 3D reformations, can portray wound channels in a way that would not be possible in the course of a conventional, destructive autopsy and can allow a reconstruction of the processes and mechanisms of trauma.
6. Currently, because of several limitations (i.e., absolute resolution of the systems, problematic documentation of superficial injuries, difficult radiographic interpretation of comingling or crossing paths, high costs, etc.) postmortem MSCT method should be considered a valid complementary tool but not a substitute for an autopsy.

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