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Case Report

Depressed fractures of the skull due to direct kick and the contribution of 3D CT reconstruction

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ABSTRACT

Depressed skull fractures occur when broken bones displace inward, meaning that a portion of the outer table of the fracture line lies below the normal anatomical position of the inner table. They typically result from force trauma, when the skull is struck by an object with a moderately large amount of kinetic energy but a small surface area, or when an object with a large amount of kinetic energy impacts only a small area of the skull. In the present case, a depressed fracture of the frontal bone was detected at the autopsy of a 52-year-old man who, according to the belated confession of the assailant, was kicked in the head. The assailant was wearing sneakers. Could such a fracture be caused "just" by a kick? In this case it was possible due to an extraordinarily thin cranial vault (0.2 cm frontal, 0.3 cm occipital), which allowed the fractures to occur from a kinetic force that might not have been sufficient with a normal cranial vault thickness. An important role in the forensic analysis of the case was played by the 3D CT reconstruction.

1. Introduction

The skull can fracture when subjected to a direct and forceful impact, often resulting from significant head trauma severe enough to break at least one bone. The different types of vault fractures include [1]:

- Simple fractures: the skull fractures without damaging the skin.
- Linear fractures: a single thin line with no additional splintering, compression, or distortion of the bones.
- Depressed fractures: fractures causing displacement of the bone towards the brain.
- Compound fractures: fractures involving a break in the skin and splintering of the skull bone.

In the case of depressed vault fractures, these usually occur due to high-energy impacts against a small surface area of the skull, often resulting in skin lesions. Without injuries on the skin, the recognition of the wounding tool may be difficult and dependent on multiple factors. To determine the force required to cause an injury and assess whether the observed injuries align with the suspected injury mechanism are also major challenges in forensic investigations.

2. Case description

A 52-year-old man was found unconscious on the ground in a supine position. Some witnesses reported that the man had argued with a young man (white, around 20 years of age, approximately 1.80 m tall, weighing 70 Kg, with an athletic build, wearing tracksuits and sneakers) moments before being found on the ground. The victim was then transported to the nearest Hospital, where he performed an urgent head CT scan. The examination revealed multiple partially displaced fractures in the left hemisphere of the cranial vault, involving both the frontal and occipital poles (Fig. 1). Subdural hematoma was also noted along the left hemisphere and the cerebral falx, associated with contuso-hemorrhagic foci in the frontal region and a small amount of subarachnoid hemorrhage in the basal cisterns. After the urgent CT scan, the man suffered from a cardiac arrest in the emergency room. Unsuccessful attempts at resuscitation were carried out.

Using the radiological scans obtained at the time of hospitalization, a 3D reconstruction of the head CT scan (Fig. 2) was performed using GE Healthcare AW server 3.2 (Chicago, Illinois, US). The 3D analysis clearly illustrated bone fragments outlining depressed, circular areas in the fractured frontal and occipital poles. Moreover, it revealed a linear, almost horizontal fracture across the left parietal bone connecting the

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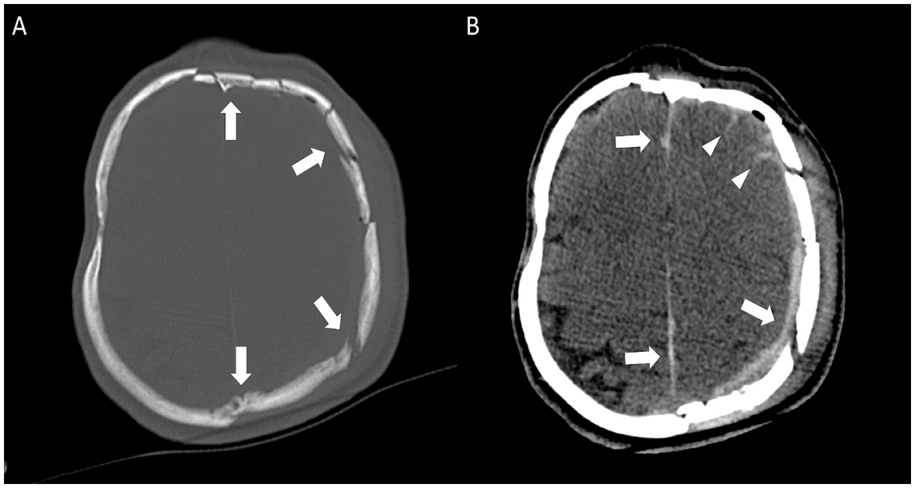

Fig. 1. Head CT scan of the patient. A) The bone window shows partially displaced fractures in the left hemisphere of the cranial vault, involving both the frontal and occipital poles (arrows). B) The soft tissue window shows subdural hematoma along the left hemisphere and the cerebral falx (arrows) and subarachnoid hemorrhage in the left frontal sulci (arrowheads).

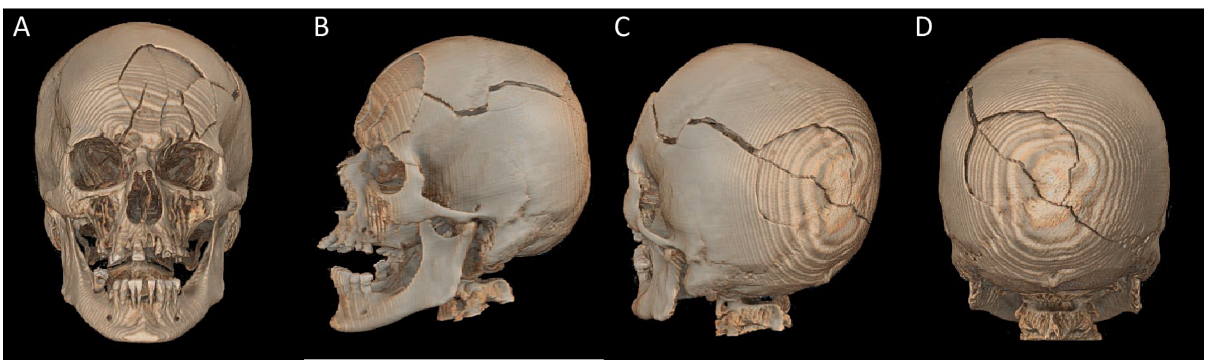

Fig. 2. 3D reconstruction of the head CT scan of the patient (A: frontal view, B: left anterior oblique view, C: left posterior oblique view; D: posterior view).

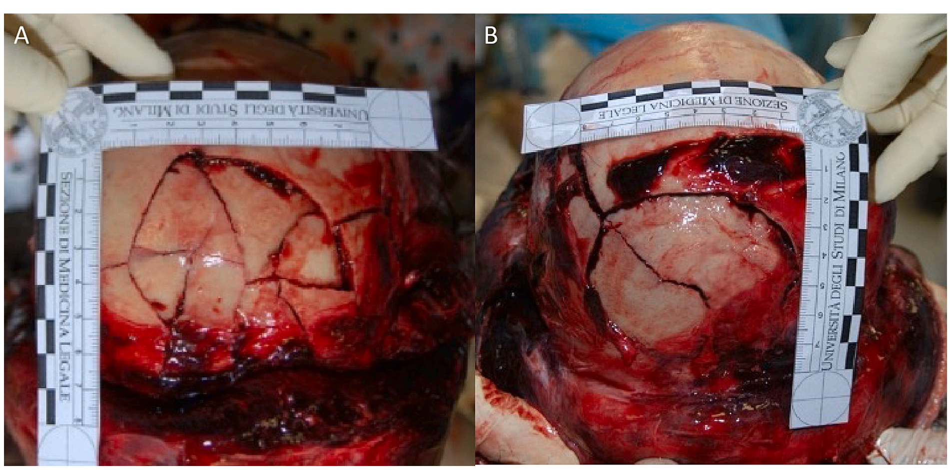

Fig. 3. Findings from the autopsy of the patient. A) frontal depressed fracture, B) occipital fracture.

two depressed polar fractures.

During the autopsy, only three superficial abrasions measuring approximately 3x1 cm were detected on the forehead. At the section two roughly round fractures of the skull were found (Fig. 3):

- one with a diameter of 6.5 cm, depressed with several bone fragments displaced inwards
- one with a diameter of 7 cm with two bone fragments displaced inwards.

Confirmation of the linear fracture of the cranial vault was observed on both sides of the fractures. According to Puppe's rule for the intersection of the skull fractures (Fig. 4) [2–4], it was established that the frontal fractures occurred before the occipital fractures, thus

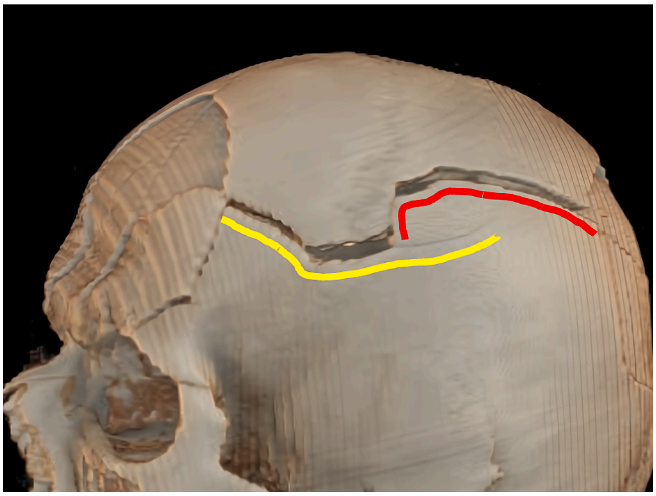

Fig. 4. Lateral view from the 3D reconstruction showing the intersection of the skull fractures. According to Puppe's rule, the frontal fractures (yellow line) was caused before the occipital fractures (red line).

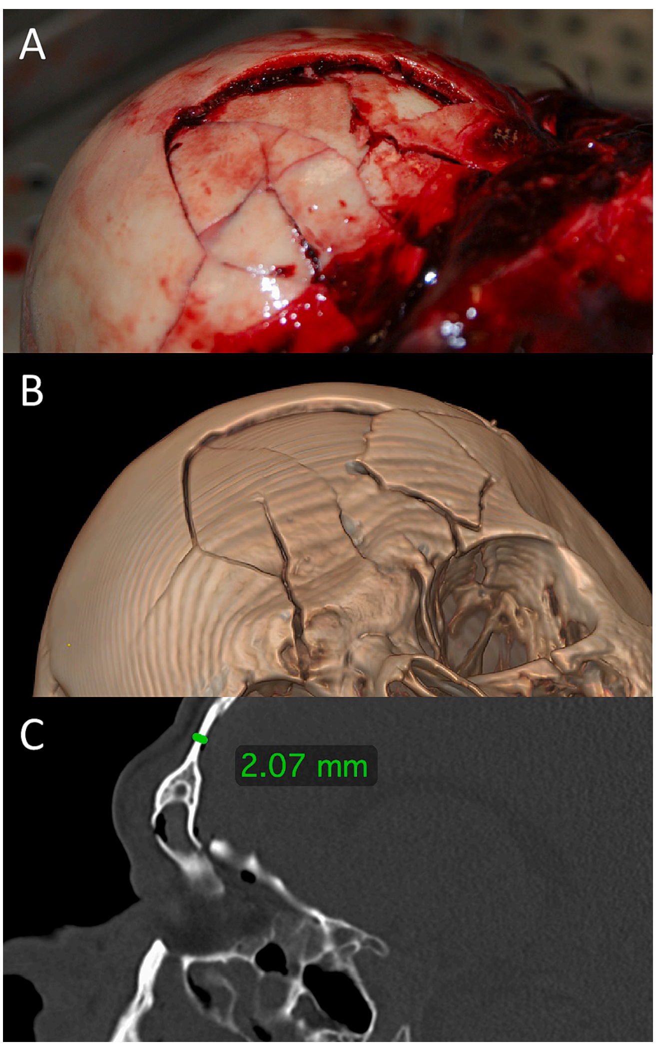

Fig. 5. Depressed frontal fracture. Note the extreme thinness of the cranial vault. A) autopsy finding, B) 3D reconstruction, C) CT measurement.

establishing the sequence of the head injuries.

The cranial vault thickness at the fracture sites showed an extraordinary thin measurement of 0.2 cm in the frontal region (Fig. 5) and 0.3 cm in the occipital region. These measurements were obtained using a digital caliper and were retrospectively confirmed on the CT scan.

There were also fractures of the left anterior cranial fossa, with extensive subdural hemorrhage and brain contusions in the frontal and occipital areas. Death was ascribed to craniocerebral trauma.

When apprehended by the law enforcements, the assailant initially tried to deny and decline all responsibility, claiming that the force of the blow was minimal. Faced with the evidence provided by the 3D CT reconstruction of the head injury and the autopsy findings, it was possible to corner the man.

The forensic reconstruction of the characteristics of the kick made it possible to identify how it was thrown with the toe forward thus concentrating more force in a smaller area (the frontal bone) and resulting in a depressed skull fracture. The posterior fractures were attributed to the impact with the ground during the fall.

According to the assailant's subsequent confession, the victim approached the perpetrator's dog and bent down towards him, prompting the assailant to kick the victim directly in the frontal area with the tip of the toe of his sneakers. The victim then fell to the ground hitting the road surface with the occipital region. The assailant was wearing sneakers with a size of 42 EU.

3. Discussion

From a biomechanical perspective, cranial fractures result from various forces affecting the motion of the body (specifically, the head), leading to ruptures in its least plastic tissue (bone). In such scenarios, the bone response to a load (strain) depends on the speed and magnitude of the applied force. In general, different types of loads produce characteristic fracture patterns [1,5]. Low-speed injuries involving a wide area typically result in linear fractures, whereas high-speed trauma tends to cause smaller, depressed fractures [6]. When force is applied over a wide surface, kinetic energy will be absorbed, leading to smaller injuries; conversely, a localized force application tends to be more destructive. In this case, blunt force trauma is considered as a low-speed injury. The curved areas of the skull, while structurally stronger due to their shape, limit the contact surface area and often result in severe injuries, although the outcome always depends on the kinetic energy produced. The shape and size of the object used to apply the load are closely associated with the resulting fracture pattern. According to Berryman and Symes [7] a typical depressed fracture due to blunt force trauma will develop through four different phases: a) low velocity impact on the skull, leading to fracture formation as a consequence of the primary inward bending of the cranial vault with surrounding outward bending, followed by inward displacement of the bony fragment due to plastic distortion; b) radiating fractures in the region of outward bending, which starts at one or more points away from the impact site, progressing both toward the impact point and in the opposite direction; c) radiating fractures stop when they meet the sutures; and d) formation of concentric fractures, perpendicular to the radiating fractures. The study by Kranioti et al. [8] showed a depressed skull fracture resulting from a horse kick, whose features mainly overlap with the depressed fractures observed in the presented case. While the kinetic force of a horse kick is not comparable with that of a human kick, the extraordinarily thin cranial vault in the presented case played a fundamental role. In a recent pilot study, Rowbotham et al. [9] described the pattern differences in skeletal injuries resulting from a one-punch, one-punch with fall and fall from standing height. Notably, no depressed fractures were found in 51 cases examined.

In the forensic literature depressed skull fractures are typically associated with high-energy impacts [10–12]. However, to our knowledge, in the literature no specific study investigates the potential of a kick with sneakers to cause frontal skull fractures in an adult subject. In previous studies, skull fractures were mainly localized to the facial bones or resulting from blows to the skull resting on a rigid surface [1,14–16]. Based on a study of 64 subjects by Lynnerup [17], the average thickness of the skull vault in adult men measures 7.044 mm (DS 1.273) in the frontal area and 7.825 (DS 1.657) in the occipital area. In another study involving1097 individuals, De Boer et al. [18] reported values respective values of 6.15 mm (DS 1.91) and 7.33 mm (DS 2.01). Additionally, Mole et al. [13] summarized that the mean peak force required to fracture the skull ranges from approximately 3 kN to 12.5 kN.

Also, the presence or absence of fractures in different cases may be attributed to various intrinsic and extrinsic variables influencing how bones respond to blunt loads. Hamel [19] demonstrated how thickness, density and landing surface make neurocranial bone suboptimal for resisting and absorbing blunt forces. However, not all relevant variables were examined. Factors such as individual kicking strength, impact velocity, and the angle of impact during a fall [9,13,19] may also influence the likelihood of fracture.

The extraordinary thinness of the cranial vault (2 mm frontal, 3 mm occipital) was pivotal in our case. This characteristic was previously detected in a study involving an elderly man with Paget's disease who experienced mild blunt force trauma from a fall [20]. In our case, no predisposing pathologies for increased bone fragility were identified. The assailant wore sneakers and was not particularly athletic or trained. Also, the almost complete absence of lesions on the skin (only small abrasions in the frontal area and no lesions in the occipital area) are indicative of the slight impact on the skin, consistent with the assailant's account. Fracture origin depends on fracture magnitude, surface area of impact and position of the loose head relative to the spine. Although many variables involved in the case could not be assessed (like the acceleration involved), it may be estimated that a force of less than 300 kg, exerted nearly perpendicular to the frontal axis of the skull, was sufficient to produce the depressed cranial fractures.

Although the skull thickness observed in this case is currently unique, the identified fracture pattern provides a valuable evidence base for forensic anthropologists, pathologists, and radiologists deriving their interpretation of the injuries resulting from this trauma. Forensic practitioners should approach the interpretation of such cases on an individual basis [21–24]. When the circumstances of the assault are unclear, the reconstruction of the dynamics of the event is fundamental, since it may also form part of the argument around the assailant's intent and, consequently, what charge the assailant should face. Subsequently, understanding which injuries result from which impact is essential. In this perspective, the 3D CT reconstruction contributes to the interpretation of head injuries in the assault, as demonstrated in our case.

Also, the routine use of 3D CT reconstruction could help forensic investigations and interpretations improving the accuracy of a case-by-case approach [21], such as the reconstruction of fracture patterns on soft tissues and bones, the exclusion of pre-existing bone diseases or alterations in the degree of ossification, the evaluation of anatomical variants and individual variability. Regarding these latter aspects, the analysis of individual differences may explain their influence on fracture susceptibility integrating the injury analysis and the reconstruction of the dynamics of traumatic events. This approach provides a more holistic understanding of the factors contributing to injuries, combining anatomical, mechanical, and situational elements to offer a complete picture of the events under investigation.

4. Conclusions

In most of fatalities resulting from cranial fractures, the cause of death, a variation of 'head injury', is not difficult to ascertain. However, establishing the precise mechanism of the head injury can be challenging, especially when the circumstances of the event are unclear. A thorough 3D CT reconstruction can aid in the interpretation of head injuries found at the autopsy.

This case serves as an example of how even minor trauma to the usually thickest parts of the skull (frontal and occipital region) can still result in major depressed fractures when the cranial vault is particularly thin. So, in response to the question "is it possible to create a depressed fracture of the skull with a direct kick?" the answer may be: "yes, if the cranial vault is much thinner than normal".

5. Declarations

This research did not receive any specific grant for funding agencies in the public, commercial, or not-for-profit sectors.

Ethics approval:

Data were acquired as part of a forensic judicial investigation and in accordance to Italian Police Mortuary Regulation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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