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Three-dimensional (3-D) imaging in post-mortem examinations: elucidation and identification of cranial and facial fractures in victims of homicide utilizing 3-D computerized imaging reconstruction techniques

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Abstract The analysis of cranial and facial fractures in skeletal remains of homicidal victims can prove challenging for forensic anthropologists and forensic pathologists in postmortem examination. In such cases, the use of 3-D computerized imaging to elucidate the fractures and patterns of injuries can provide strong medical evidence that is very useful during litigation and at trial. The authors describe 3-D reconstructions of the skull performed as part of forensic postmortem examination in a recent victim of homicide.

Key words Forensic anthropology · Blunt force trauma · 3-D imaging · Patterned injury · Trajectory

Introduction

Based on previous applications, 3-D imaging from computerized tomography (CT scanning) can have great value in courtroom presentation to juries. Innovative applications of radiology have been used for the identification and treatment of clinical pathology and trauma, in plastic surgery, in forensic science for facial reconstructions, and in anthropology for the study of osteological remains and mummies. The application of 3-D imaging has moved from the clinical setting to the layman setting, such as museums, classrooms and internet displays and instruction. For example, 3-D reconstructions of the faces of victims and trauma allow for greater illustration of the detail of the crime and a greater understanding of how and what crime(s) occurred when presented to a jury (Oliver et al. 1995; Riepert et al. 1995; Sherouse et al. 1990).

It is important to point out that 3-D imaging does not create new data. Creating 3-D images allows for the exploration of more data (already present but not observable), better presentation of the data and directs attention for further investigation (Oliver et al. 1995). Three-dimensional imaging of the skull also allows for the movement of the cranium so that all angles and aspects may be observed and for the removal of unwanted layers of soft tissue or artifacts. Furthermore, various models may be saved and compared, which may be important for facial reconstructions or postulating possible trajectories. One difficulty is potential warping of the image (Oliver et al. 1995). In some experimental work, 5–10° of warping occurred (Oliver et al. 1995). As Oliver et al. (1995) pointed out, warping may be overcome with more research and experimentation of validation methods.

This paper presents the first use of 3-D imaging from CT scanning applied to craniocerebral injuries in a current forensic case. Descriptions of fracture patterns resultant from blunt and sharp force injuries in a victim of homicide are elucidated from 3-D imaging. As a result, 3-D imaging provides an opportunity to present critical aspects of craniocerebral trauma, a clear illustration of blunt and sharp force trauma and hypothesizes plausible injury trajectories suitable for courtroom presentation.

Materials and methods

The remains of the deceased were examined by a team of a forensic pathologist, a forensic anthropologist, and a radiologist at the Lancaster County Coroner's Office in Lincoln, Nebraska USA. The trauma identified through osteological and radiographic study were compared. An unrestricted post-mortem examination was first completed by the forensic pathologist. A complete osteological study of the skeletal remains were then analyzed by a forensic anthropologist. Radiographs of the entire head and body and CT scanning of the head were completed. Finally, 3-D imaging of the CT scan film was employed to identify and reconstruct fracture patterns of the skull following dry bone analysis.

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Osteological analysis of the remains included determination of sex, the age-at-death, ethnic identification, metric and dental analyses, and documentation of trauma following the standards described by Teixeira (1982), Ubelaker (1989), Buikstra and Ubelaker (1994), Marino 1995 and Loth and Hannenberg (1996).

The computerized cranial reconstructions were completed through the use of a General Electric CT/1 scanner. The skull was positioned in a padded head holder. The orbital-meatal line was aligned with the axial CT slide plane and 1 mm thick helical images were obtained through the skull with a slice spacing of 1 mm. A KV of 80 was used along with an mA setting of 80.

A 3-D model was built from the axial set of helical images using the manufacturer's 3-D reconstruction program. The 3-D images were produced using a bone algorithm. The initial surface rendering was then changed to a maximum intensity projection (MIP) and the image modify program was used to selectively remove objects from the model, such as the head holder and padding positioned outside the skull for support during scanning.

Surface rendering was then restored and the model was rotated into various positions for photography on a laser printer. The ambient light intensity and shading for the x-axis and y-axis were adjusted to permit optimal visualization of each image. The depth of the 3-D algorithm were also adjusted for best visualization of the deep structures.

Finally, the skull was "cut" electronically in axial and oblique sagittal planes to permit better visualization of the internal structure and enable demonstration of plausible trajectories of blunt or sharp force impacts. Electronic "sectioning" and spatial rotation of the computer 3-D model enabled photography which optimally displayed the pathology for presentation. Electronic plots of the probable trajectories from the frontal entrance wound to the left temporal fossa and from the vertex to the floor of the left anterior fossa were also plotted and photographed. Finally, inward beveling and marginal defects of the wounds were enhanced and fractures were plotted and photographed allowing for the plausible theorizing regarding force trajectory.

Case history

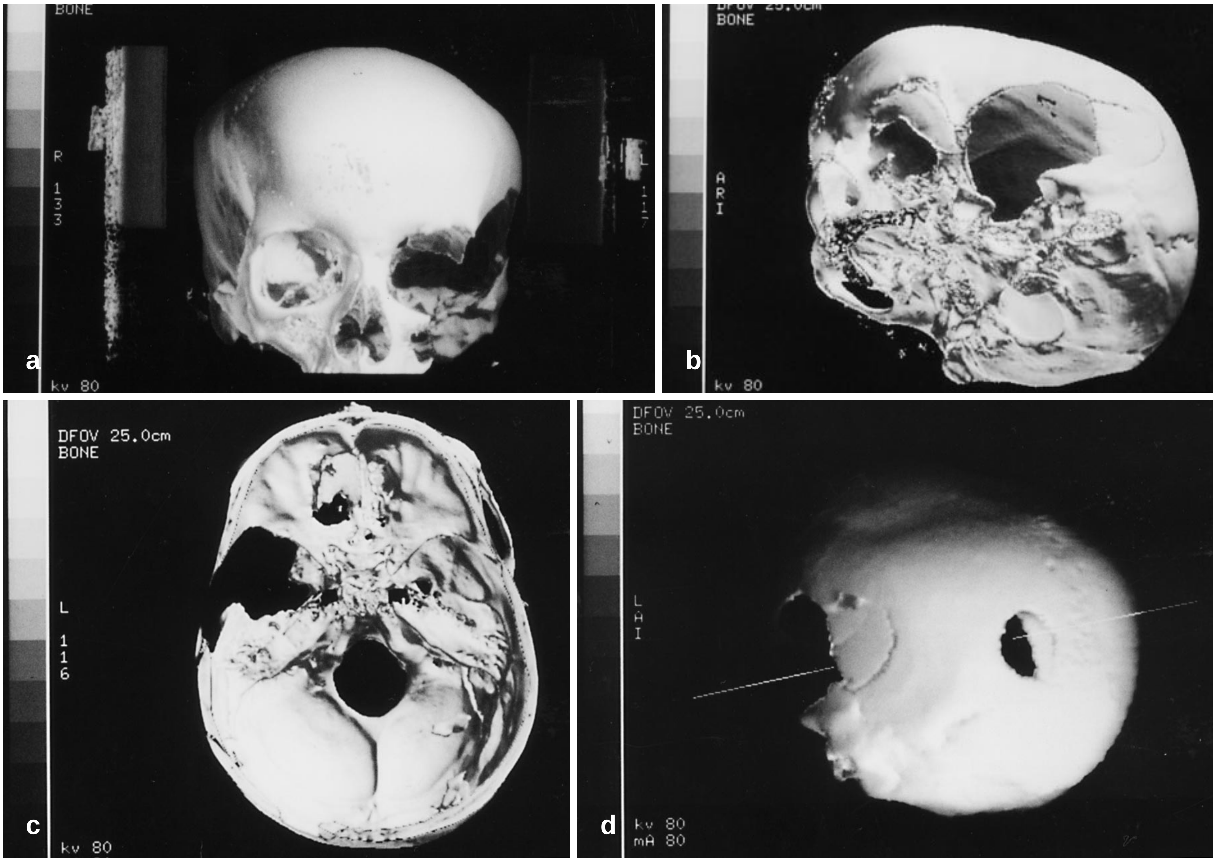
The extensively decomposed body of an unidentified female victim was discovered in an overgrown perimeter of a park (Fig. 1). A sheet was wrapped around the body. Through entomological analysis, the time since death was determined to be 6–9 weeks. The body was deposited in mid-July to the beginning of August and was recovered at the end of September. The musculoskeletal system and internal organs were absent due to extensive decompositional changes, however, the epidermis was mummified (Fig. 2). Overall, the skeletal remains were complete and well preserved.

Forensic anthropological analysis identified the age-at-death, sex, and race of the victim. Also, activity patterns were reconstructed from analysis of the skeleton (Myers 1996).

The sex, age-at-death, race, stature, and idiosyncratic conditions determined through skeletal analysis were released to the press. The family of a missing women matching these characteristics contacted the authorities. Finally, a positive identification was confirmed through the comparison of dental records. The cause of death was determined to be severe multiple blunt force trauma and sharp force trauma to the head and trunk. The manner of death was ruled to be homicide.

Fig. 1 Crime scene showing the victim of multiple blunt force and sharp force trauma. Note the extensive skeletonization and decompositional changes of the victim in the woods where the body was found several weeks after death occurred

Fig. 2 The skull with parchment mummified facial skin and scalp still attached to the skull at autopsy



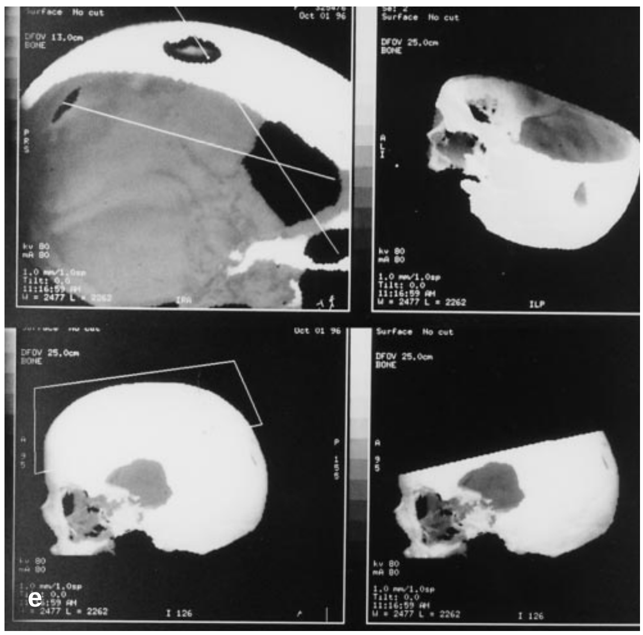


Fig. 3 **a** Three-dimensional (3-D) imaging of the cranium and face. **b** The facial skin and scalp have been eliminated by the 3-D imaging CT scanning technique. The patterned fracture on the lateral aspect of left eye orbit is easily visualized. **c** Electronic section and spatial rotation of the computerized 3-D model allows for detailed visualization of the patterned semi-circular fracture of the left temporal bone and the base of the skull. **d** Details of the fracture of the left occipital bone. Note that the 3-D imaging CT model allows one to demonstrate the possibility of trajectory of the impact causing the occipital fracture and defect. This feature would be very useful in forensic analysis of gunshot wounds and deeply penetrating sharp force trauma of the cranium. **e** Composite photographs showing how the electronic sectioning and spatial rotation of computerized 3-D imaging CT model allow one to optimally display the cranial and facial pathology for presentation which is especially useful during court testimony

Forensic autopsy findings following 3-D imaging and anthropological analysis

Evidence of post-cranial trauma, identified through forensic autopsy findings following 3-D imaging and anthropological analysis, is first described. Second, craniocerebral trauma identified through forensic autopsy after 3-D imaging and anthropological examination is discussed. Note that the fracture numbers (1–9) are arbitrary and were designated for the purpose of data collection and description (Fig. 1). They do not imply the order in which the fractures occurred on the skull or their relation to one another.

Craniocerebral trauma identified through forensic autopsy and after 3-D imaging and anthropological examination, included six cranial and three mandibular fractures (Fig. 3). These fractures resulted from direct blunt force trauma. One cranial fracture, fracture #8, on the frontal bone resulted from sharp force trauma. Of the cranial and mandibular fractures identified through osteological analysis, fractures #2 and #8 were patterned fractures.

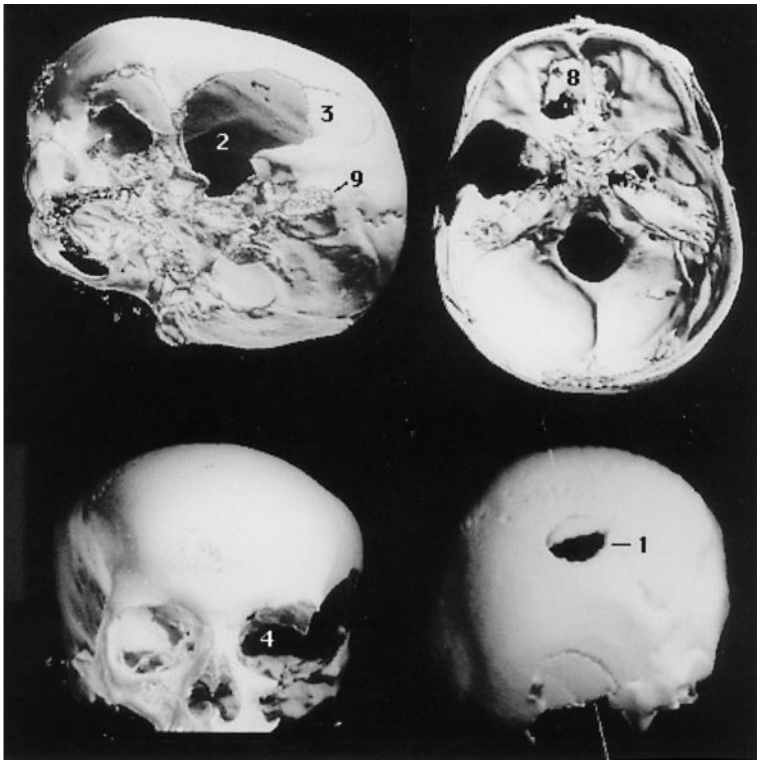


Fig. 4 This series of images illustrates how 3-D imaging can be used to show the location and extent of fractures to juries. The numbered cranial fractures are 1) oval fracture located on the left occipital bone, 2) a patterned semicircular defect located in circular fracture on left temporal bone, 3) linear fracture extending from the left temporal region onto the parietal bone, 4) a composite of multiple individual fractures which have displaced the left facial skeleton and left anterior cranial vault, 8) a fracture due to blunt force injury on the lateral aspect of the left eye orbit and 9) left mastoid fracture

Results

The results of 3-D imaging included the following. Due to the advanced stage of decomposition, the brain was not present and only a few small areas of desiccated tissue were present on the outside of the skull which could be seen on the CT images and digitally removed during the 3-D reconstruction (Fig. 3b). No metallic projectile fragments were present in the specimen. Measurements of fractures #2, #3, and #4 from the 3-D images were found to be more precise. The cause of death was blunt force trauma and the manner of death was homicide.

Discussion

The particular area of the skull which is impacted, the thickness of the skull scalp and hair, and the direction of the impact affect the outcome of the injury, and are important considerations when describing the morphology of the injury, constructing three-dimensional computerized models, or hypothesizing about possible impact trajectories. In general, blunt force impact on the upper temporal or parieto-temporal areas causes fissured fractures which run obliquely downwards across the temporal area (Fig. 3c). Furthermore, a heavy impact on the side or top of the head often leads to a vault fracture which also runs into the base of skull, usually across the floor of the middle cranial fossa along the anterior margin of the petrous temporal bone, to enter the pituitary fossa. The findings in this investigation are consistent with both of these generalizations.

Types of fractures affecting the cranium may be linear or depressed (Smith et al. 1987). Linear fractures represent about 70% of cranial fractures and generally point to the site of impact (Smith et al. 1987). Depressed skull fractures are radiating or concentric and may be beveled in appearance (Smith et al. 1987). In the case study presented, both linear and depressed fractures were present. Furthermore, fracture #2 was beveled in appearance. Due to the elasticity of cranial bones, fractures may reflect the shape of the object which impacted the bone (Spitz 1995). Both fractures #2 and #8 were patterned fractures. Furthermore, fracture lines from impacts which occur after the initial force are arrested by the fracture lines of the first impact (Spitz 1995). Due to arrested fracture lines in this case study, it was determined that fracture #3 occurred after fracture #4.

The clinical post-mortem examination is most often complimented by plain film radiographs. These are able to detect most fractures and foreign objects and offer the advantages of simplicity and cost effectiveness. Computed tomography is often used in the clinical setting to evaluate complex trauma areas such as facial fractures. When multiple fragments or foreign objects are present or when spatial relationships are critical, 3-D CT reconstructions may play a valuable role. Reconstructed 3-D images may provide additional information in selected post-mortem examinations as well. Non-destructive sectioning can allow examination evaluation of projectile paths from entrance to exit. Once physical sectioning of a specimen is performed, it cannot easily be put back together and sectioned in other planes. The 3-D CT images allow optimal presentation of the spatial relationships of fractures and projectiles in a manner that is much easier to grasp by juries or laymen. Once projectile vectors and entrance/exit wounds have been identified by the forensic examiner, the evaluation, presentation and communication of these is optimized by the ability to present side-by-side raw images with annotated 3-D images showing projectile paths and entrance/exit relationships. The surface rendering capabilities of 3-D imaging may enhance facial reconstruction in victims identification. In complex cases, 3-D imaging offers the potential to optimize dissection planning.

In conclusion, the use of three-dimensional imagery to analyze cranial and facial fractures in skeletal remains of homicide victims serves to refine fracture measurements, detail patterns of trauma and show trajectory paths involving multiple injuries (Fig. 3e). This method also has the potential to be used in the validation of bullet path trajectories (Fig. 3d). Information obtained through 3-D imaging may provide critical elements of evidence in identifying and convicting the perpetrator of homicide or illustrating the case for a jury. Generally, the presentation of visual aids to a jury such as 3-D imagery elucidated from CT scanning allows greater detail of the crime/events and greater understanding of the nature of the trauma itself.

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