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TECHNICAL NOTE

GENERAL

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Reverse Engineering—Rapid Prototyping of the Skull in Forensic Trauma Analysis

ABSTRACT: Rapid prototyping (RP) comprises a variety of automated manufacturing techniques such as selective laser sintering (SLS), stereolithography, and three-dimensional printing (3DP), which use virtual 3D data sets to fabricate solid forms in a layer-by-layer technique. Despite a growing demand for (virtual) reconstruction models in daily forensic casework, maceration of the skull is frequently assigned to ensure haptic evidence presentation in the courtroom. Owing to the progress in the field of forensic radiology, 3D data sets of relevant cases are usually available to the forensic expert. Here, we present a first application of RP in forensic medicine using computed tomography scans for the fabrication of an SLS skull model in a case of fatal hammer impacts to the head. The report is intended to show that this method fully respects the dignity of the deceased and is consistent with medical ethics but nevertheless provides an excellent 3D impression of anatomical structures and injuries.

KEYWORDS: forensic science, rapid prototyping, selective laser sintering, maceration, biomechanical trauma analysis, postmortem, computed tomography

Rapid prototyping (RP) is the generic term for automated construction techniques such as selective laser sintering (SLS), stereolithography, three-dimensional printing (3DP), which use virtual 3D data sets to fabricate solid forms in a layer-by-layer technique. SLS is mainly used in the automotive/aerospatial and manufacturing industry as an intermediate between planning and production stage and serves to validate the usability, for example, of newly developed assembly parts. So far, medical applications of RP techniques include the planning stage in maxillofacial and reconstructive surgery (1,2) and modeling of abnormal anatomical conditions (3–5). Furthermore, stereolithographic models have been used in an anthropological setting (6). In forensic casework, there is a growing demand for reconstruction models that simulate and visualize complex anatomical structures. The assignment of the maceration of body parts following medico-legal autopsy poses great ethical problems on both the state attorney and subsequently the forensic experts, because the forensic examination shall be performed using cosmetically acceptable techniques respecting the dignity of the deceased. Furthermore, macerated skulls frequently fail to show fracture systems in their original position after an impact. With the increasing importance, availability and application of radiological methods, for example, computed tomography (CT) and magnetic resonance imaging (MRI) scans, new possibilities have come into reach of the forensic expert (7,8). Despite this progress, computed models often lack some of the plasticity macerated bone parts offer to the court.

Here, we present a first application of RP in forensic medicine using CT scans for the fabrication of a human skull model in a case of fatal hammer impacts to the head, in which the maceration of the skull was assigned by the state attorney to clarify the chain of action including the number of impacts to the head. The report is intended to show that this method fully respects the dignity of the deceased and is consistent with medical ethics (9) but nevertheless provides an excellent 3D impression of anatomical structures and injuries.

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Methods

Digital CT scans were performed with a reconstruction interval of 600 μm using a Somatom Definition 64 scanner (Siemens Medical Solutions, Forchheim, Germany) and then transferred into an iso surface model of the skull using the software package Osirix V3.3.2 (Osirix Imaging Software, GNU GPL). Following, the surface model was exported as a high-resolution STL (Surface Tessellation Language) file (Fig. 1*a*). For the RP part, we used the SLS method (Sinterstation 2500 Plus; DTM Corporation, Austin, TX) because of its high 3D resolution and the durability of its prototypes (Fig. 1*b*). Fine polyamide with a grain size of 60 μm (PA2200; Electro Optical Systems, Munich, Germany) was chosen for optimal delineation of the approximated interslice distances.

Medico-legal autopsy was performed 10 h postmortem (Fig. 2*a*). For the skull preparation, we employed an oscillating saw followed by brain examination using the Flechsig technique (Fig. 2*b*). Severe traumatic brain injury in combination with blood aspiration was ascertained as the cause of death. Subsequently, facial soft tissue was dissected using the mask technique to remove the skull without further affection of skin surface integrity. The skull was then macerated (enzymatic maceration for 4 days at 60°C, acetone treatment for 4 days, bleaching process for 2 days in hydrogen peroxide [10%]). Thereafter, reconstruction of the macerated skull was performed attaching fragmented bone pieces with unambiguous breaking edges to the skull rudiment (Fig. 1*c*).

FIG. 1—*Right frontotemporal view of the 3D volume reconstruction (Osirix V3.3.2) (a), rapid prototyping/selective laser sintering (RP/SLS) model (b), and the macerated skull (c). Note the plastic impression of the depressed comminuted fracture of the temporal region in the RP/SLS model.*

Results

Reconstruction analysis of the macerated skull (Fig. 1*c*) revealed a comminuted fracture system of the right temporal/parietotemporal and frontal region as well as both orbitae and zygomatic bones. The right temporal bone showed a comminuted fracture with multiple irregularly shaped bone fragments passing into the frontal bone, where two almost ring-shaped fracture lines were discernable. The respective bone fragments had been depressed or displaced (being attached to dura and skin tissue). Taken together with skin surface inspection, which revealed three distinct lacerations in the respective areas, we concluded that at least three blows to the head (two in the temporal and one in the frontal region) had been administered by the assailant.

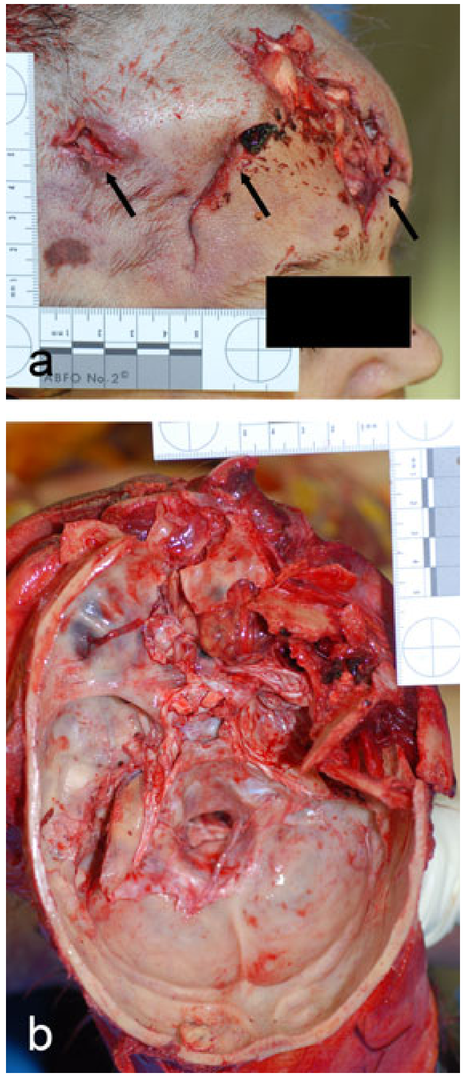

FIG. 2—*Right frontotemporal photograph of the head with three distinct lacerations (arrows) upon external examination (a). Preparation of the skull showing a comminuted fracture of the right frontotemporal region and orbitae (b).*

Analysis of the laser-sintered prototype (Fig. 1*b*) showed the very same fracture pattern in general, whereas additional breaking edges and accordingly bone fragments caused by the saw cut were not found. Furthermore, bone fragments that could not be fitted in the macerated skull (e.g., in the frontal bone) were shown in their posttraumatic position within, beneath, or above the skull level. The fractured skull areas displayed a plastic image, for example, of the depressed comminuted fracture of the temporal region.

Discussion

RP is an umbrella term for a number of modern engineering techniques, some of which have already found their way into parts of the medical field, for example, in surgical planning procedures

(1,2), illustration of abnormal anatomical conditions (3–5), and anthropological specimen (6). As radiological techniques such as CT and MRI scans have gained in importance and availability as an additional tool of forensic diagnostics over the last years, 3D data sets needed for the virtual reconstruction (Fig. 1*a*) are usually available in those cases, where hitherto maceration of the human skull was the only method allowing for haptic evidence presentation in the courtroom. RP/SLS of 3D data sets allow for the rapid and cost-efficient reconstruction of pre-autoptical "untouched" anatomical conditions and thus gives a very plastic impression of the injuries and consequently the forces exerted on the respective body part. In particular, SLS offers valuable additional information concerning the *in situ* position of each bone fragment involved in the formation of a complex fracture system. Furthermore, in cases, where a maceration of the skull is not deemed suitable because of ethical, religious, or cultural reasons, CT scan–based RP might be a useful alternative, which is consistent with the medico-ethical claim to preserve the personal dignity of the deceased (9). In the present case, the RP/SLS model was used in court to demonstrate multiple impacts on the head. Especially in regard to relatives being present in the courtroom, it proved to be more acceptable than maceration preparations, which justifiably tend to evoke strong emotions.

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