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Case Report

Biomechanical Examination of Blunt Trauma due to Baseball Bat Blows to the Head

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Abstract We report a case of a homicidal baseball bat blow to the head of a woman resulting in multiple skull fractures and an experimental setting to establish the striking energy. The victim and the baseball bat were digitized by multislice computed tomography (MSCT). Based on this data, 3D models were generated. With these models, the impact angle could be determined using 3D visualization software. The reconstruction of the impact action was performed using synthetic skull-brain-models and a drop-tower, in which a baseball-bat-module was directed at the models. We scanned the models after impact and compared the resulting fractures to the victim's skull. The energy necessary for the resultant fractures was found to be between 80 and 100 Joules (J), an energy range far above the fracture threshold of the human skull of 14.1 to 68.5 J.

Keywords forensic medicine; blunt trauma; baseball bat; reconstruction; virtopsy

1 Introduction

The post-mortem analysis and interpretation of blunt trauma in homicide victims may be a complex task for forensic pathologists. The use of three-dimensional methods such as 3D surface scanners and multislice computed tomography (MSCT) can provide means for clarification of the course of events.

The interpretation of fractures is essential for identifying the impact angle, sequencing blows and establishing the characteristics of the object responsible for an injury, as discussed by Reichs [6]. The use of 3D-surface-scan and multislice computed tomography enables the determination of impact direction as well as a comparison of resultant and artificial fractures, as Thali et al. described [10]. The force of a blow with an object in a physical dispute or homicide can be of relevance at court. If one knows the maximum energy that an assailant can deliver, the judicial authorities can compare the inflicted energy with the maximum striking energy of the assailant and draw conclusions on the intent, that is, with maximum force intended to kill as opposed to a comparably slight blow aimed at "merely" injuring the opponent.

Several studies in the past dealt with the fracture thresholds of the human skull [2,7]. These studies used either dry bone, embalmed or unembalmed cadaver heads. Animal tests provided physiological and injury data, but these results must be translated to the in vivo human [4,5]. As Thali et al. described previously [11], the application of synthetic skull-brain models enables the reconstruction of injuries. In a drop tower, where parts of weapons can be fixed and dropped at different heights, fractures can be recreated, allowing for the determination of delivered energy.

2 Methods and material

2.1 Case report

After heavy rain, two police officers found the fully-clothed, drenched body of a 42-year-old woman lying on her front on a path beside a lake. External inspection of the corpse revealed a laceration of the right ear, a linear indention of the scalp at the right side of the head with palpable skull fragments, a crush-wound at the back of the head and another at the left side of the forehead (Figure 1). The post-mortem interval was estimated at 9 ± 3 hours. Police combing the vicinity found a maple wood baseball bat in bushes nearby.

The body was brought to our forensic institute for surface scanning, MSCT and subsequent forensic autopsy.

Subsequent investigations and confessions showed that the woman was lured to the crime scene by an acquaintance and struck at least three times against the head with the maple wood baseball bat by two men waiting for her.

2.2 3D surface scan

In order to scan the scalp of the victim, we shaved the head and used a TRITOP/ATOS III system (GOM, Braunschweig, Germany) as described previously [8,9].

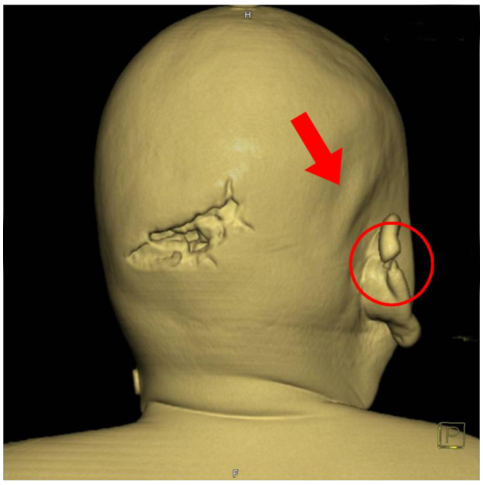

Figure 1: 3D-model of the victim. Notice the massive laceration, as well as the visible depression (arrow) above the cracked external auricle (circle).

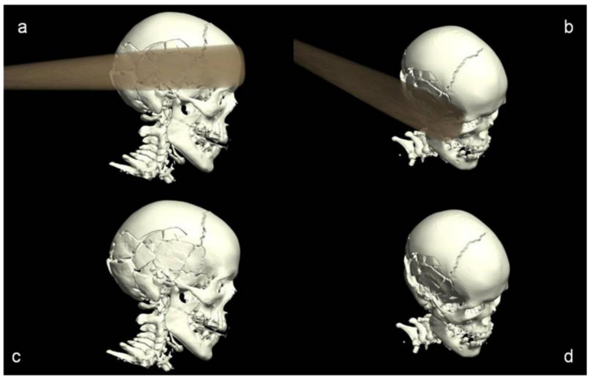

Figure 2: (a) and (b) Determination of impact direction using the 3D-surface scan of the inflicting weapon in overlap with the victims 3D-surface. (c) and (d) Multiple fractures of the woman's skull.

This system consists basically of one central projection unit and two digital cameras mounted beside the projector. A fringe pattern is projected onto the surface of the object, which is recorded by the two cameras. Based on the principle of triangulation, 3D coordinates are calculated by the scanning software ATOS, resulting in a digital 3D model of the surface of the victims head. Digital photography of the surface of the object of interest from different angles can, using the TRITOP software, add color information to the otherwise black-and-white 3D model. The digital 3D models of the head were used to overlap the victims injuries and the injury-inflicting weapon (3D Studio Max Software) to determine the impact direction (Figure 2). The use of 3D Studio Max Software enabled the comparison of original and artificial fractures.

Figure 3: Drop-tower, where the inflicting weapon part was directed to the models.

2.3 CT examination

The victim and the injury-inflicting baseball bat then underwent multislice computed tomography (MSCT) on a Somatom Emotion 6 scanner (Siemens Medical Solutions, D-91301 Forchheim, Germany) before autopsy. The victim was scanned with 6 × 1 mm collimation, the baseball bat with 6 × 0.5 mm collimation. The increment was 0.7 mm for the victim's scan and 0.3 mm for the weapon. Using a CT workstation (Leonardo, Syngo CT software, Siemens Medical Solutions, D-91301 Forchheim, Germany), three-dimensional models were created.

2.4 Reconstruction

Due to differing confessions regarding the succession of the baseball bat blows, a reconstruction of the injuries was necessary.

In a drop-tower, as previously described by Bolliger et al. [1] (Figure 3), the distal end of a similar maple wood baseball bat was attached to a weight (4.3 kg) and dropped at

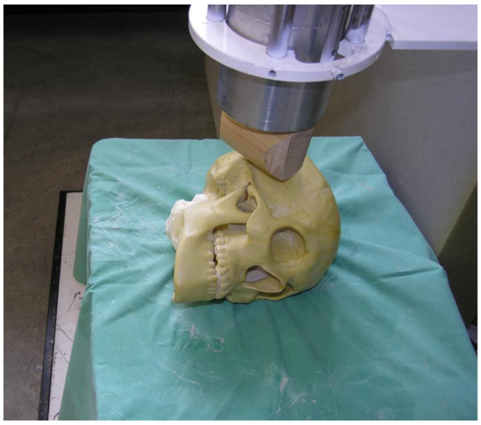

Figure 4: Synthetic skull model targeted by the front part of the baseball bat.

different heights to skull-brain models (Figure 4), evaluated by Kneubuehl and Thali [3]. The height of drop was calculated accordingly of the necessary energy, therefore a height of 1.89 m arose for an energy of 80 J, as well as 2.36 m for 100 J. The skull model was fixed using a modeling clay. After dynamic impacts in the drop-tower, the models where scanned in MSCT and compared to the original fractures.

2.5 Artificial skull

An anatomically correct "skull-brain model" was used for all simulations. The model exhibits the characteristics of a real skull and breaks during external forces as the human skull.

The skulls (Synbone AG, CH-7208 Malans, Switzerland) are composed of polyurethane with a three-coat construction which simulates the tabula externa, the diploe, as well as the tabula interna. The periosteum is replicated by a thin cover of latex. Furthermore, the skull was filled with liquid gelatin (10%), which simulates the human brain.

2.6 Physical bases

2.6.1 Kinetic energy

The kinetic energy E_{kin} is the energy which a body has due to its movement state. The following equation describes the kinetic energy of a body object in movement:

$$E_{\text{kin}} = \frac{1}{2} \cdot m \cdot v^2.$$

2.6.2 Potential energy

The potential energy E_{pot} is the energy which a body has due to its position in the gravitational field. With the drop impact tests necessary for this work the body received its potential energy by the drop height. The potential energy is given as

$$E_{\text{pot}} = m \cdot g \cdot h.$$

In this special case, the kinetic energy can be calculated analogously to the potential energy. According to the law of energy conservation, energy is constant in a mechanical system free from friction. Furthermore, the entire energy can be distributed to different mechanical forms of energy. Before the free fall, while in a passive (immobile) state, there is potential energy, the kinetic energy exists while striking.

In the drop impact tests, the aerial friction could be neglected as the results would not be influenced significantly by aerial friction.

Therefore, the kinetic energy of the blow is equal to the potential energy in this case.

3 Results

3.1 CT examination findings

The right lateral region of the victim's skull demonstrated an expanded, comminuted fracture with bending-burst fractures to the base of the skull.

The back of the head showed a fracture line of the occipital bone with additional fracture lines extending into the right side of the head. Additional fractures above and below the fracture line at the back of the skull could also be seen.

3.2 3D surface scan findings

The victim's surface showed a depression of the right head and a laceration of the auricular cartilage, where the area of impact was visible. Furthermore, a laceration of the occipital area was visible.

3.3 Autopsy findings

The victim was 157 cm tall and weighed 55 kg. In addition to the external findings, autopsy presented an extensive, spider-net-like comminuted fracture of the right temporoparietal bone. The underlying cerebral cortex was crushed (so-called coup injury), as was the cortex of the left temporal lobe (so-called contre-coup injury). Under the crush-wound of the back of the head was a terraced fracture but no relevant brain damage was seen.

Due to the not immediately lethal nature of the cerebral injuries, the sparseness of the livores and the pallor of the inner organs, the cause of death was deemed to be exsanguination due to the scalp lacerations.

3.4 Reconstruction findings

The greatest agreement between experimental and original fractures arose at energies of 80–100 Joules (J). Furthermore, the experimental analysis showed that the first impact to the right lateral side of the skull resulted in the fracture line in the occipital area and probably would have been lethal.

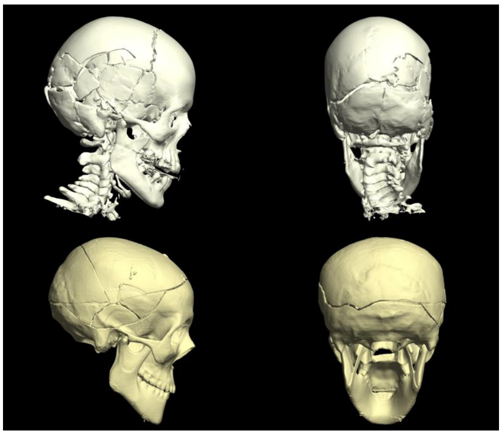

Figure 5: Comparison of the original fractures (above) and the artificial fractures (below).

However, compared to the original fractures, the artificial fractures showed a lesser extent of fracturing and fewer fragments (Figure 5). Fracture lines out of the comminuted fracture system in the lateral area continue in both cases into the occipital, frontal and parietal areas, though the original fracture lines ended in the coronal and lambdoid sutures.

4 Discussion

The multidisciplinary approach of dynamic and virtual methods indicated that the impact energy needed to cause the woman's injuries reached 80 to 100 Joules (J).

The determination of the impact direction enabled the dynamic reconstruction with synthetic skull-brain models.

Regarding the Head Injury Criterion (HIC) from which it can be derived that the probability of a cranial fracture is with an HIC of 1000 with 48%, which corresponds to the impact energy of 47 J, as well as the fact that the human skull breaks at energies between 14.1 J to 68.5 J, as Yoganandan et al. published in [12], our results show that the woman's head was struck well in excess of the human skull threshold, thus suggesting that she was struck with full force, a finding indicative of willful homicide.

The impact energy needed to cause the woman's injuries almost equates to the average value for the impact energy of 97.2 J which results from a study being prepared [13] for the investigation of the maximum impact energy using baseball bats.

Differences in fracture dimension are explicable by the absence of sutures in the synthetic skull models. According to the Puppe-rule, the artificial fractures would also have ceased in the coronal and lambdoid sutures. Furthermore, the attached front part of the baseball bat features a smaller impact surface than a whole baseball bat, thus the expansion of fractures was reduced. The experiment also showed that the fracture in the occipital area occurred by the blow to the side of the head and not by a blow delivered to the back of the head. However, the blow to the back of the head did cause additional fractures above and below the fracture line to the occipital area.

Another noteworthy difference to a real-life situation is the experimental setting itself. In the case examined here, the baseball bat struck the head of the woman in an upright position, that is, the head rested on the neck. A blow to the head held to the neck by joints, ligaments and muscles may give way to a certain extent, thus reducing the actual impact energy, as opposed to an artificial head fixed with modeling clay, which cannot deflect as readily. The impact energy in the real-life situation may therefore have been even greater than the energy required for the creation of the fractures in our experimental setting, thus underlining the assumption that the perpetrators struck the woman with full force.

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