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Biomechanical investigation of naso-orbitoethmoid trauma by finite element analysis

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Abstract

Naso-orbitoethmoid fractures account for 5% of all facial fractures. We used data derived from a white 34-year-old man to make a transient dynamic finite element model, which consisted of about 740 000 elements, to simulate fist-like impacts to this anatomically complex area. Finite element analysis showed a pattern of von Mises stresses beyond the yield criterion of bone that corresponded with fractures commonly seen clinically. Finite element models can be used to simulate injuries to the human skull, and provide information about the pathogenesis of different types of fracture.

Keywords: naso-orbitoethmoid trauma; facial trauma; finite element analysis; biomechanics

Introduction

The naso-orbitoethmoid complex comprises the confluence of the orbit, nose, maxilla, ethmoid sinuses, frontal bone, and floor of the frontal sinus. Markowitz et al classified fractures of the area into 3 types (I to III) according to the involvement of the medial canthal tendon.[1] They can be part of a panfacial fracture, or localised. Kelley et al reported that they account for about 5% of all facial fractures and we have also found this in our experience.[2]

For many years, a large number of fractures of the naso-orbitoethmoid complex were sustained in road traffic accidents, but as cars have become safer they now occur less often.[3] Nowadays, most facial fractures are caused by interpersonal violence and sports accidents,[4,5] and these impacts differ considerably in velocity and power from those sustained in road crashes. Fractures caused by a single impact might seem of minor clinical relevance compared with those sustained in road accidents, which can be panfacial and associated with other life-threatening injuries, but the region consists of many anatomical structures and is close to parts of the anterior skull base where smaller fractures might have severe consequences – for example, intense bleeding from injury to the ethmoid vessels. We therefore examined the biomechanical performance of the bones in the area when hit by single impacts, and the distribution, direction, and extent of the progress of stress in a transient dynamic finite element analysis.

Methods

We constructed a model of the midface to make a finite element analysis of fractures of the naso-orbitoethmoid

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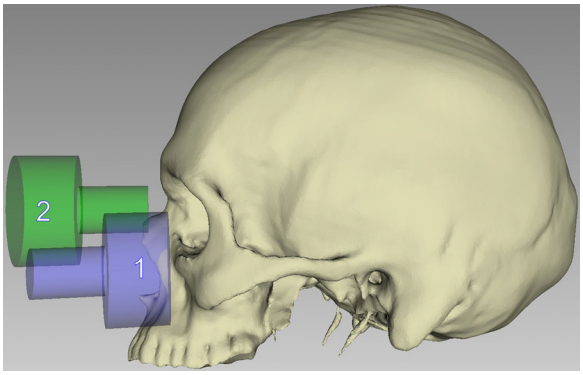

Fig. 1. Impact by virtual impactors for study designs 1 and 2.

complex caused by a single impact. It consisted of 736 934 10-node tetrahedrons. Data were derived from the computed tomography (CT) dataset of a healthy 34-year-old white man (Siemens Somatom Plus 4 Volume Zoom, 1 mm contiguous slices). After manual segmentation the dataset was exported into VRML (virtual reality modeling language), triangulated (VWorks 4.0® Cybermed, Korea), and imported into ANSYS ICEM CFD 12.0.1® (ANSYS Inc, Canonsburg, USA).[6] To assign individual variables of the bony material to each element, we translated grey-scale values of the CT Hounsfield scale into information on bone density, and used a BoneMat script to calculate Young's modulus for each element.[7,8] Two different study designs were chosen: the medial third of the infraorbital rim (Fig. 1), and the junction between the nasal bone, maxillary nasal process, and lacrimal bone (Fig. 2).

To simulate the impact from one single fisticuff, a virtual brass impactor (weight 412 g, density 8.4 g/cm^3), Young's modulus of 100 000 MPa, and Poisson's ratio of 0.37 were

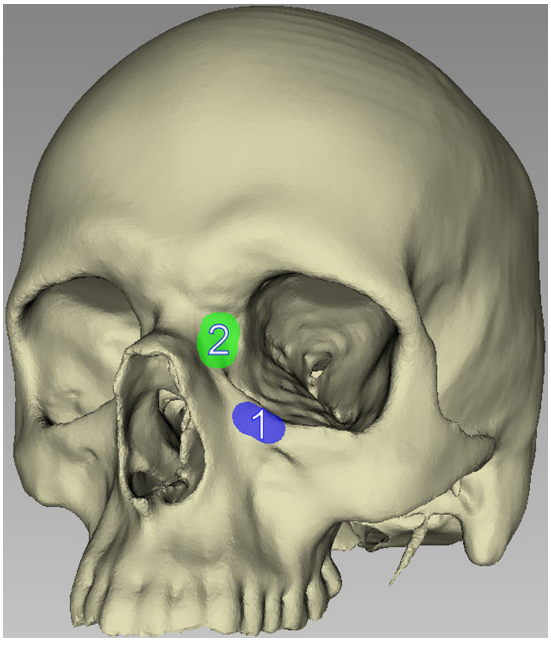

Fig. 2. Contact zones between impactor and bone for study designs 1 and 2.

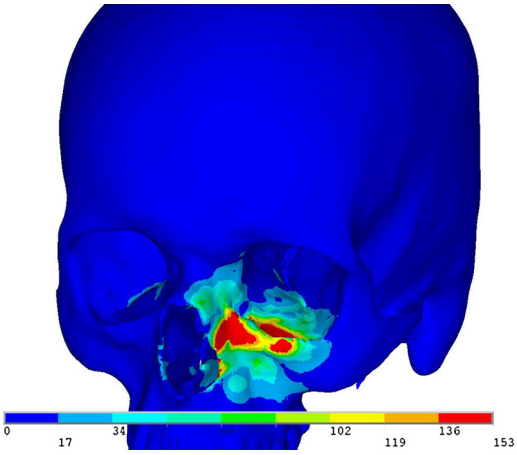

Fig. 3. Von Mises stresses in study design 1 that correspond with paranasal fractures of the medial inferior orbital rim and fractures in the anterior orbital floor (scale is von Mises stresses in MPa).

modelled according to the experiments of Waterhouse et al.[9] The velocity of impact was 6 m/second. We used a transient mode of simulation as the interaction between the skull and impactor depended on time. The model was fixed at the occipital condyles in all degrees of freedom. We assumed von Mises stresses of 150 MPa for the yield criterion of bone in the skull.[10] According to the regulations of our Institutional Review Board, approval was not needed for this investigation.

Results

In design 1, finite element analysis found a total impact of 7200 N for 1.3 msec. Von Mises stresses of more than 150 MPa, which corresponded with fractures, were seen in the medial inferior orbital rim paranasally, and in the anterior orbital floor (Fig. 3).

In design 2, finite element analysis showed a total impact of 6980 N for 2.6 msec. Von Mises stresses of more than 150 MPa were seen in the medial orbital wall. The contralateral medial orbital wall was also affected, but here the yield criterion was not reached. High stresses even spread to the occipital bone (Fig. 4).

In both designs minor stresses spread to the ipsilateral Le Fort I plane, but did not involve the anterior base of the skull or the bony optical canal. The pattern of the areas where von Mises stresses exceeded the yield criterion is consistent with typical fracture patterns seen in many patients (Figs. 5 and 6).

Discussion

When investigating the biomechanics of facial trauma it is difficult to generate a practical and ethically acceptable study design that will deliver valid and reliable information. In the past cadavers were often used. Nowadays, Le Fort's studies of 1901[11,12] would not be feasible for ethical reasons and