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Preliminary Numerical Simulations to Investigate the kinematics of Infant Head Impact.

*** Ghaidaa A Khalid [1], R. Prabhu [2], Allan Mason-Jones[1], Peter S Theobald[1], Shwe P Soe[1], Michael D Jones[1].**

[1]School of Engineering, Cardiff University, Cardiff, UK

[2] Centre for Advanced Vehicle Systems, Mississippi State University, Mississippi, USA

*****KhaidGA@cardiff.ac.uk

ABSTRACT

Presented is the development of a simulation that allows for preliminary investigation of impact to a 10 day old infant head. A computer-aided drafting (CAD) model is reconstructed from high resolution computerised tomography (CT) scan images and meshed for finite element analysis (FEA); soft tissue responses were defined using recently derived material properties. It is anticipated that the FE model will be used to investigate the paediatric head response during impact conditions, to provide a better understanding/prediction of injury biomechanics.

Keywords: *Finite element analysis; 3D rendering; image extraction; impact simulation; injury prediction*

1. Introduction

Traumatic brain injury (TBI) is the leading cause of death and disability among the paediatric population [5]. Most TBI is a result of either a fall, or motor vehicle interaction [4]. Injury biomechanics research plays a vital role in providing guide lines that can inform design engineers and reduce head injuries by developing preventions strategies. Additionally, an understanding of the head impact response and injury mechanisms can help clinicians distinguish between accidental and inflicted TBI. Computational models of the head, associated with injury biomechanics, represent a powerful tool that can be used to achieve all these goals.
Many researchers have focused on the biomechanics of adult head injury, using finite element models (FEMs). In paediatric impact biomechanics, however, FE paediatric head models are few due to several limitations the limited availability of material property data, quantitative age-dependent anatomical data, and paediatric impact response data.

2. Methodology

2.1 Geometrical Acquisition and Meshing Generation

Axial head CT scans of a 10 days old infant were selected and construct cranial geometry using Mimics Software (Materialise; Leuven, Belgium). Mimics softweare uses gray scale image values from CT scans to segment the model into regions by defining a threshold value. All pixels within the upper and lower threshold of grayscale were defined into the region of interest, and regarded as the cross - section of three dimensional (3D) geometry. Certain tissues have a distinguished threshold, such as the cranial bones (parietal, occipital, and frontal bones) and skull base that has a particularly intricate geometry, including the multiple foramina, processes, internal cavities and branching structures, which were segmented using the threshold filter. The cervical vertebrae and mandible were removed. Other tissues displayed similar gray value intervals making their segmentation, based on threshold values, difficult. In this case an interactive segmentation method was applied to isolate single tissues from surrounding tissues, such as the brain. Fontanelle and sutures, which consist of fibrous connective tissues, filled the gap between skull plates. Possessing gray scale values very close to the cranial bones made segmentation, using the segmentation tools, problematic. They were created and developed by using wrapped, Boolean operations and manual editing tools. A detailed 3D representation of major tissues within the head was developed, including cranial bones, skull base, sutures, fontanelle and brain as shown in Figure 1. Subsequently, the autoremesh function was applied by the Mimics Remesher (3-matic v10) with different quality parameters and element mesh size, to optimise the mesh quality and reduce the number of elements, to achieve more accurate results with a reduced computational time.

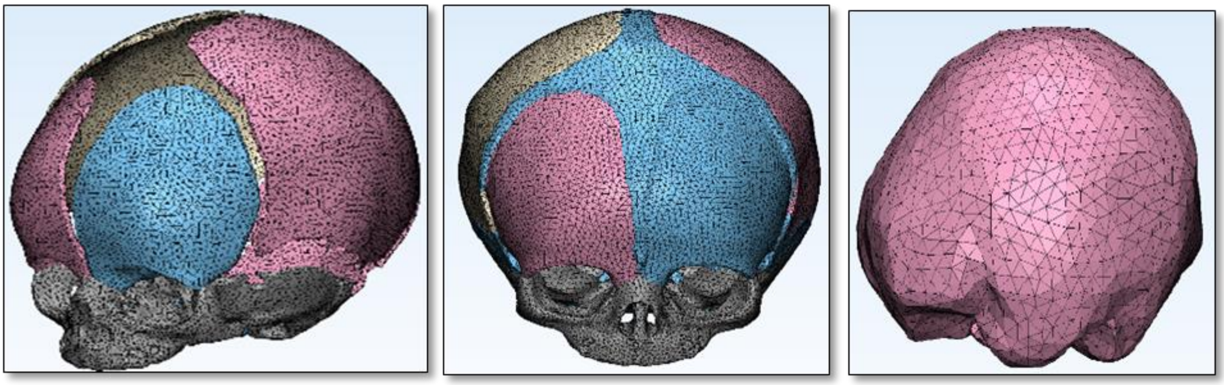

Figure1: Finite element (FE) mesh of the cranial bone, and sutures of a 10 day old infant through an (a) front oblique view, (b) front boss view, and (c) front oblique view of 10 day old infant brain.

2.2 Material Properties

Previous attempts at producing validated infant head models have represented the material properties of the cranial bone as homogeneous and isotropic [6 &8]. At birth, however, paediatric cranial bone has a visible fibre orientation due to the bone trabecula, supported by the orthotropic response in foetal cranial bone reported by McPherson & Kriewall [7]. High-rate testing of infant bone conducted by Coats & Margulies [1] also revealed that infant bone is inhomogeneous, with the parietal and occipital bone having different stiffness properties. These differences in the elastic modulus between the parallel and perpendicular specimens confirm the significant anisotropic material proprieties in the immature cranial bone. Thus, infant cranial bones were modelled as orthotropic- elastic, with different elastic moduli parallel and perpendicular to fiber orientation. The suture was modelled as elastic - isotropic, whilst a gelatin substance was used for the brain [3].

2.3 FE Simulation

The environment in the FE solver (Abaqus/ Explicit™ 6.12) was established, following development of the FE model. A frictional contact coefficient of 0.2 was used to model the interaction between the FE head and a rigid plate [2]. A tie constraint was applied, for the interaction between the skull-sutures, and skull-brain. General contact sliding was used to model the interaction between the head model and rigid plate. The model was rotated and translated (Figure 2), so its position corresponded with the rigid surface for a specific impact location on the head. The model was dropped from 30cm onto the occipital region with an impact velocity of 2.4 m/s, as shown in Figure 2, to provide a comparison with Coats & Margulies [2], who investigated an impulse force-time response for a 1.5 month old infant head model. It is anticipated that the FE model will be validated with additional experimental response data, to provide an effective tool for quantifying nature and magnitude of skull and brain deformation and subsequent prediction of the risk of injury during a traumatic event.

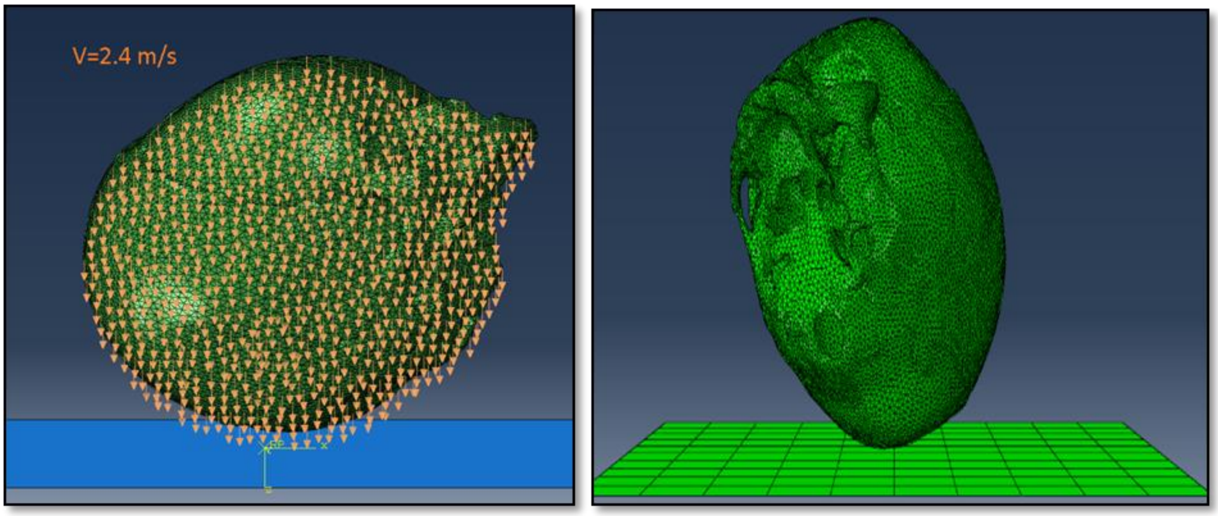

Figure 2: Illustration of (a) the boundary value problem of an occipital impact to a 10 day old infant head (with skull, sutures, and brain), and (b) Finite element (FE) simulation of the same.

3. Results and Discussion

Impact to the occipital region was simulated for a fall of 30 cm height, resulting in a velocity equal to 2.4 m/s (Figure 2). The results, presented in Figure 3, represent the energy dissipation of the model during a 20 ms FE simulation. The total energy is relatively constant throughout the simulation. Energy output can be used to evaluate whether an Abaqus/Explicit simulation is predicting an appropriate response. Evaluating the energy curve, at the beginning of the simulation the components of the head are in free fall, meaning relatively high kinetic energy (ALLKE). The initial impact deforms the head, reducing the kinetic energy; thereafter, the continuing head deformation causes transfer of kinetic energy to internal energy (ALLIE) within the head i.e. the internal energy increases as the kinetic energy decreases. Another important energy output variable is the total artificial energy (ALLAE), which is a substantial fraction of the internal energy. Artificial strain energy should not be a substantial percentage of the overall internal energy of the system. In this case, it is a very small percentage of the overall internal energy and thus, the model is considered to be valid, at least from the perspective of element behaviour and possibility of error due to meshing. The peak impact force from our model (a 10-day old child), is similar to the impact force reported by Coats & Margulies (1.5 month old child), as described in Figure 4 [2]. Both of these models show very similar material responses, though there is a difference in impulse force response that is perhaps related to subtle variations in anatomy, age and non linear geometrical differences. The mass of 1.5 month old model was 0.87 kg, while the head model of 10 day old equated to 0.46 kg; thus, higher impact forces and shorter durations appeared in the impulse force – time responses, which was 3.54 Ns for 1.5 month old child and 1.82 Ns from our simulation.

4. Conclusions

High resolution CT scan images were used to construct a finite element model of a 10 day old infant head, consisting of accurate geometries for the skull, sutures, fontaneelles and brain. Obtaining the sutures from CT images was shown to be possible by using thresholding and manual editing. The HU range for the sutures is relatively large and further studies need to be conducted to obtain a more precise and accurate HU range. Preliminary results are presented to show how the paedatric head tissue boundaries were segmented to build a detailed, accurate anatomical model. We have successfully meshed our existing model and, in combination with low strain rate material response data, provide relatively accurate results versus reduced computational time.

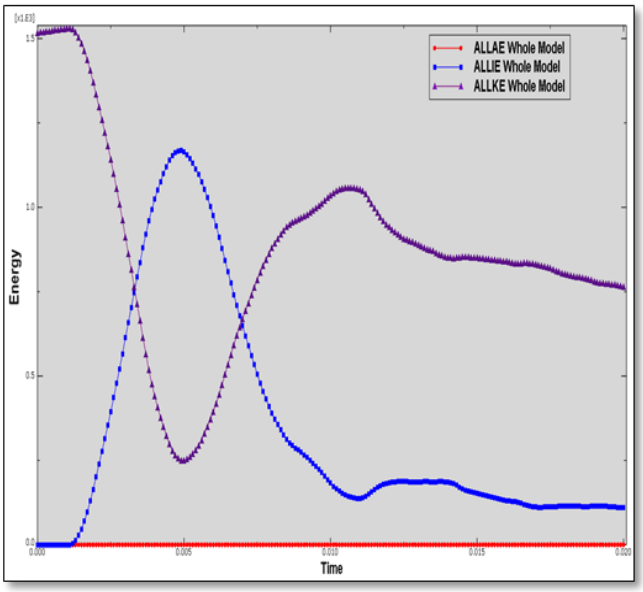

Figure 3: Energy - time curves for an occipital impact from a 30cm height drop.

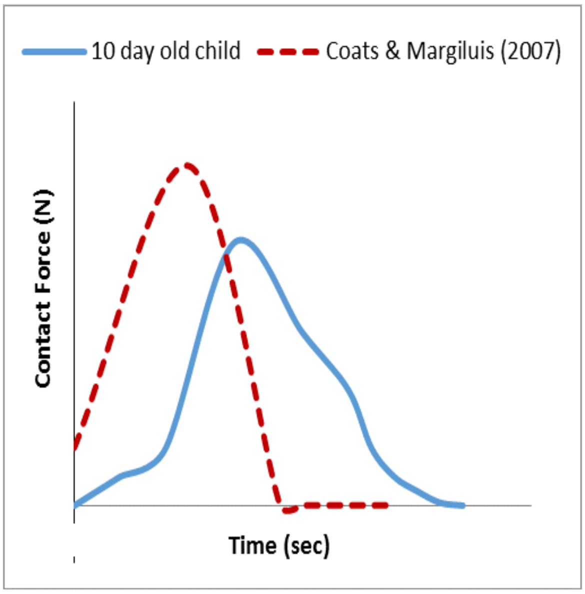

Figure 4: Force-time contact curve for the occipital area from a 30 cm height drop.

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