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A finite element study to quantify the relationship between masticatory stress and prognathism

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INTRODUCTION

In anthropology, the finite element method (FEM) is frequently applied to determine the validity of hypotheses concerning the adaptation of biological form to suit functionality. Different geometries are analysed, and based on the predicted displacements and/or stresses, conclusions are drawn regarding which geometry is better suited to perform a particular function. In this project, we demonstrated the ability of the FEM to predict patient-specific stress distributions due to a variation in facial form. The outcomes of this project have potential application in forensic science and facial reconstructive surgery.

CRANIOFACIAL VARIATION

Evolutionary biologists and dental practitioners have been interested in the study of sub-nasal maxillary alveolar prognathism for quite a while and the history thereof has been debated in the literature [4,8]. Upon visual inspection, this is one of the most noticeable morphological characteristics of the human skull, characterised by either one or both jaws projecting forward, clearly influencing the general shape of the maxillofacial region of the skeleton.

Bone deposition and resorption is known to occur when sufficient high or low stresses are present within the skeletal structure [2,7,11]. For this reason, the skull is presumably thicker in areas of higher stress. The aim of this study is to investigate what effect mastication induced stress has on area specific thickness for varying facial form considering incisor and molar bite force in a prognathic and non-prognathic skull.

MASTICATORY-INDUCED STRESS IN THE HUMAN CRANIA

Two skulls were selected for analysis based on gnathic index (the distance from pr to ba divided by the distance from n to ba in **Figure 1**) and sufficient dentition from the University of Pretoria skull collection. A medical computer tomography (CT) scanner was used in creating scans of the selected geometries. Using these scans as image stacks, a triangulated three dimensional surface mesh was extracted after a thresholding procedure where adjustments are made on the grey scale. In this step, attenuation of a CT scan is performed to highlight bony morphology and eliminate unwanted material picked up by the scanner.

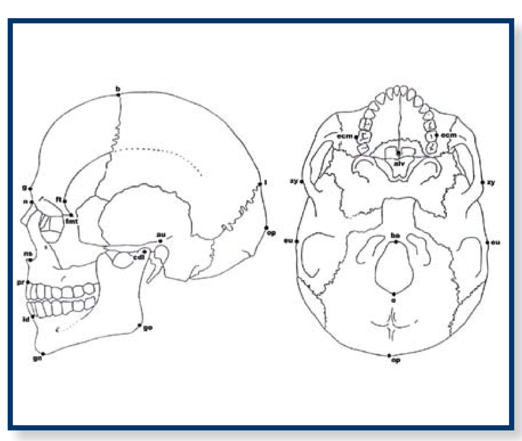

Figure 1

Figure 2

Intersecting and inconsistent triangles as well as the effects of post-mortem trauma and decay had to be taken into account, therefore the extracted surface representations were edited and smoothed. Taking into account that exact stress values are not required and this study is mainly focused on the variation in stress pattern, a four-noded tetrahedral finite element mesh was created from the final surface representation. The prognathic skull and numerical surface representation of it is visible in **Figures 2 and 3** respectively.

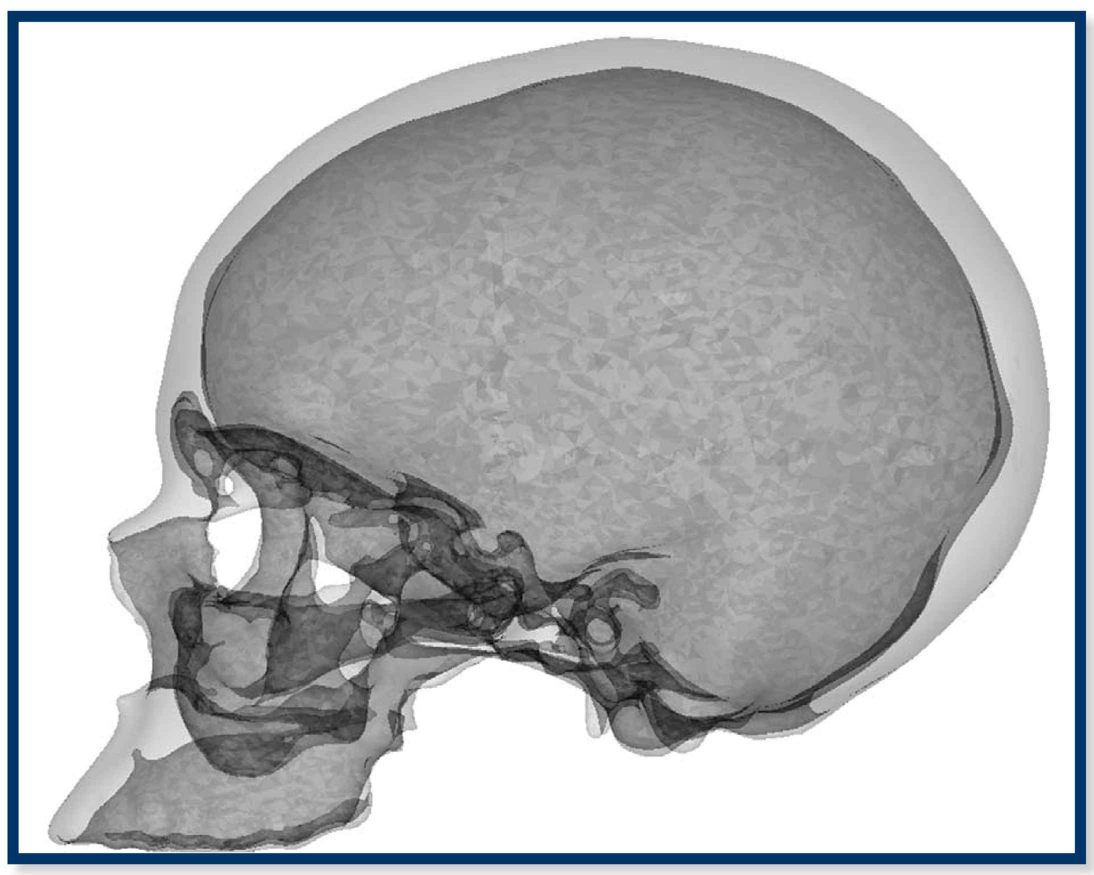

Figure 3

The nature of bone and modelling bone has been the focus of considerable research and significant variation in material properties have been documented for a range of different bones and within different areas of the same bone structure [2,4,5,7,11].

Comparing only the stress fields produced by mastication; however does not require the accurate simulation of bone to the extent that exact values for stress are recovered. For similar analyses done in literature [5,10], isotropic bone material properties have been found capable of producing realistic stress patterns and considering the highly-reduced level of effort this entails, the same assumption was made to model the full skull and teeth with a single linear elastic material. This means that the bone model used in the simulation had the same properties in all directions.

Muscle action during the cycles of mastication is different for working and balancing sides [6]. For this stress simulation, the left side of the skull was chosen as the side of the dental arcade where bite force is applied resulting in mastication forces far higher than on the balancing side. Here, force values used were determined from literature while scaling forces on the right with factors obtained from a study on muscle activity during mastication [1,9].

Forces were applied to nodes in the region representing the sites of muscle attachment in the direction of muscle attachment to the mandible. Reaction forces are then determined at the temperomandibular joint (TMJ), where the mandible hinges on the skull (point cdl in **Figure 1**), for a vertical bite force at the molar and incisor. All forces are then scaled, resulting in an identical force on the teeth for both skull geometries. The skulls were scaled and then also rotated so a line through the equivalent nodal coordinates of the TMJ would be exactly parallel to the x-axis.

Figure 4 contains some of the results on determining boundary conditions. Here, the contribution of the four muscle types on the bite force at the left first molar and TMJ are presented visually along with the total force balance. The von Misses stress field for a full molar bite analysis is visible in **Figure 5**. Here, both skulls are presented with the prognathic skull on the left and non-prognathic skull on the right.

CSIR researchers are using numerical techniques to assist anthropologists to test the validity of their hypotheses concerning the adaptation of biological form to suit functionality.

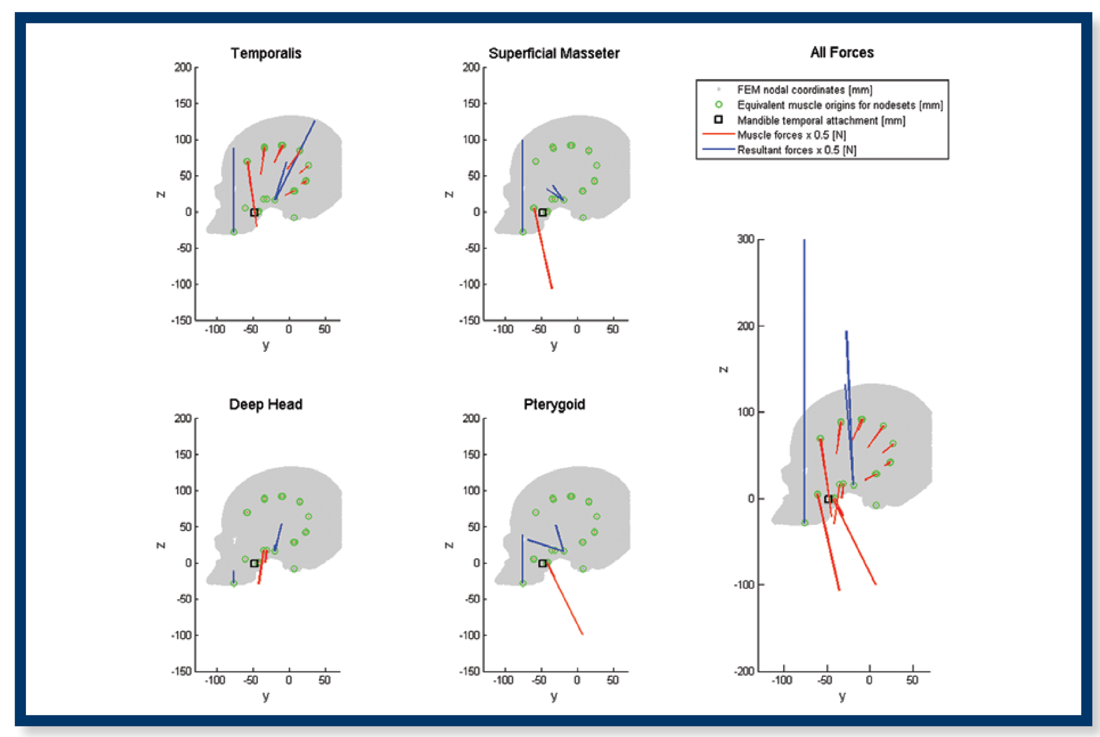

Figure 4

CONCLUSION AND FUTURE WORK

By modelling patient-specific geometry and boundary conditions, Advanced Mathematical Modelling can provide anthropologists with assistance in numerical tools to test a hypothesis. In this way, research can be done in functional morphology that could result in better understanding human evolution and how biological form is adapted for specific need. The need to handle patient-specific geometry has also resulted in the development of tools to extract and register features from geometric data. When completed, this will aid a user in doing statistical analysis from digital geometries and enable the rapid generation of numerical models for patient specific geometry.

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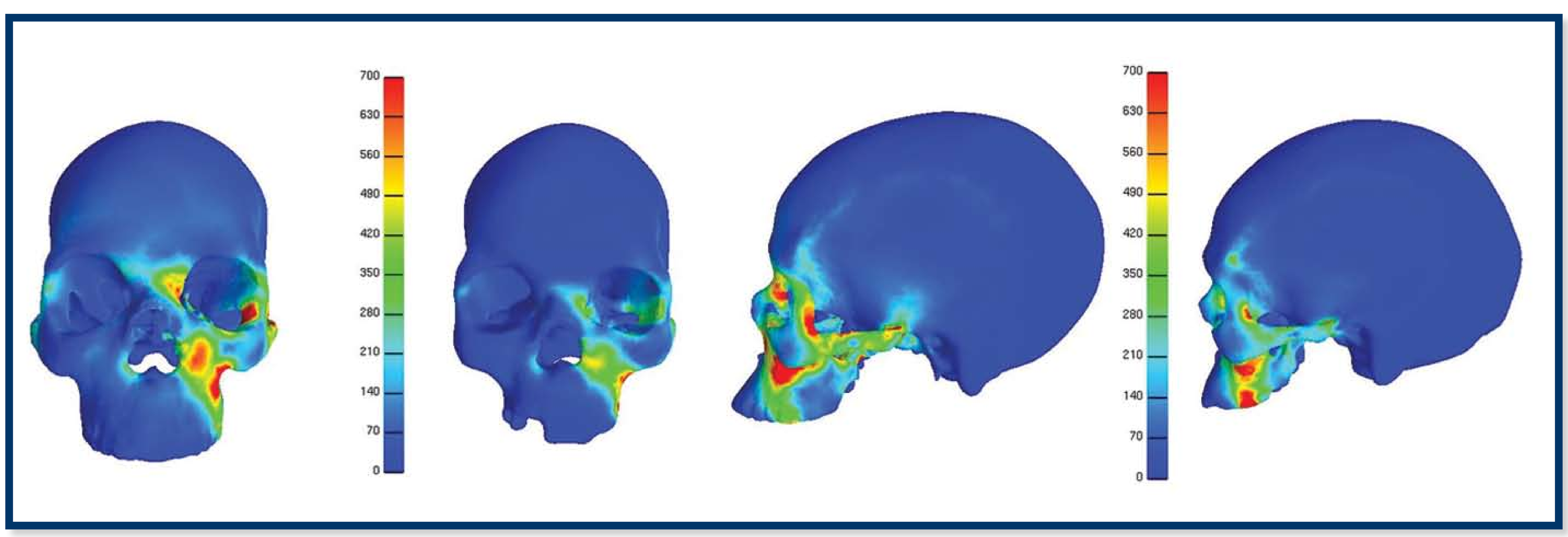

Figure 5

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