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Towards the Development of a Combined Rigid Body – Finite Element Model for the Investigation of Temporomandibular Joint Loads

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Abstract: *Temporomandibular joint disorders (TMD) are among the most prevalent human syndromes. Due to the complexity of the masticatory system, the development of TMD is not fully understood. Investigations of joint loads could lead to a better understanding of TMD. Hence, this project aims to use a novel biomechanical model of the masticatory region for the investigation of temporomandibular joint (TMJ) loads. CT data of a healthy person were acquired to create detailed models of the bony structures of the masticatory region. Additionally, MRI scans using a special TMJ imaging sequence were performed to acquire a high-resolution representation of the soft tissue structures of the TMJ for different static postures. The maxilla and mandible were represented as rigid bodies. The condylar and articular cartilage and the TMJ disc were represented as finite element (FEM) structures. In the future, we aim to use the combined Rigidbody/FEM model to gather insight into the mechanisms that underlie pathologies of the TMJ.*

1 INTRODUCTION

The masticatory apparatus is an essential part of the human body that is constantly used for every-day tasks like speaking, chewing and breathing. Dysfunctions of this system lead to severe impairments concerning speech and mastication [1].

Various conditions, affecting the mandible or the dentition, can lead to a range of problems in the temporomandibular joint (TMJ). The TMJ articulates the mandible to the skull. The TMJ is a synovial joint that connects the glenoid fossa of the temporal bone and the condyle of the mandible, hence every mandible is connected to the skull via two separate TMJs [2]. The disorders of the TMJ are collectively named temporomandibular joint disorders (TMD) [3].

Even though TMD affects approximately 20% of the western population [4], the main etiology behind it is not fully understood. The lack of understanding of the mechanisms and origin of TMDs can be partially attributed to the morphological and mechanical complexity of the TMJ itself. The jaw region is the only human system that is composed of two joints connecting the same bony structures, namely the skull and the mandible. Moreover, the complexity of the muscular system in this rather small anatomical region is peculiar [5].

Changes in disc shape, positioning as well as joint loading, could give a valuable insight into the early stages of disc displacement and possibly other causes for temporomandibular disorders. Computer models have potential to help with such analysis and have been previously proposed with simplified TMJ representations [6–8]. Hence, the presented study aims to develop detailed models of the TMJ structures for various movements. These models will be used to analyze changes in disc shape, disc position and relative position of the disc compared to the skull and condyle, as well as stress and strain of the TMJ disc.

2 MATERIAL & METHODS

Imaging data were acquired from one healthy volunteer. Ethics approval was obtained from the institutional review board of the Medical University of Vienna. CT data were acquired to create detailed models of the bony structures of the masticatory region. Furthermore, an MRI scan using a head coil in a closed mouth position was acquired to define specific muscle and tendon paths. Additionally, MRI scans using a special TMJ imaging sequence were performed to acquire a high-resolution representation of the soft tissue structures of the TMJ. The scans were collected for different mandible positions (using silicone bite blocks) in order to localize the disc for different static simulation tasks.

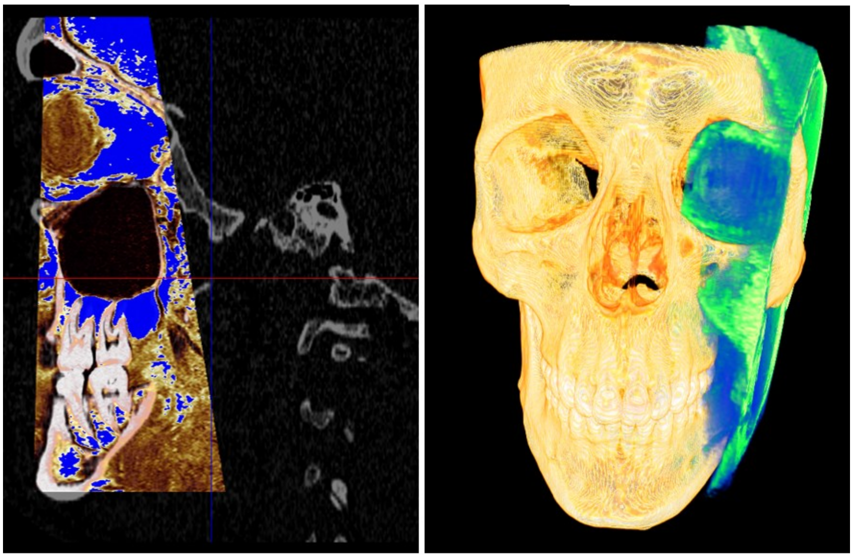

Figure 1: Registered CT and MRI data for closed mouth position (left: overlaid sagittal slices; right: renderings of CT (yellow) and MRI (green/blue) data)

Registration of image volumes was performed semi-automatically in Amira 3D™ using normalized mutual information and the conjugate gradient method (Figure 1). Segmentation of boney structures from CT was performed semi-automatically. Segmentation of the TMJ disc was performed manually by an expert. The mandibular condyles were segmented semi-automatically from MRI for all mandible positions. Afterwards, meshes were imported into Meshmixer and processed for simulation purposes. The model was built in the ArtiSynth modeling toolkit [9] (www.artisynth.org). The maxilla and mandible were represented as rigid bodies and the condylar and articular cartilage and the TMJ disc were represented as finite element structures. In the future, jaw muscles will be modeled using Hill-type line-based muscle models. Since CT data were only acquired in the closed mouth position the mandible had to be repositioned for the investigations. This was done by registering the mandible to the previously segmented condyles (from MRI). To verify the mandibular position the bite blocks that were used for image acquisition were scanned using a surface scanner and fitted between the teeth of the model. Plaster models of the proband's dentition were fabricated and scanned using a surface scanner and the high-resolution representation of the dentition was added to the model. Changes in disc position and disc thickness have been analyzed using Artisynth. In the future, the changes in stress and strain of the temporomandibular disc will be analyzed through coupled rigidbody/FEM simulations in the ArtiSynth modeling toolkit (Figure 2).

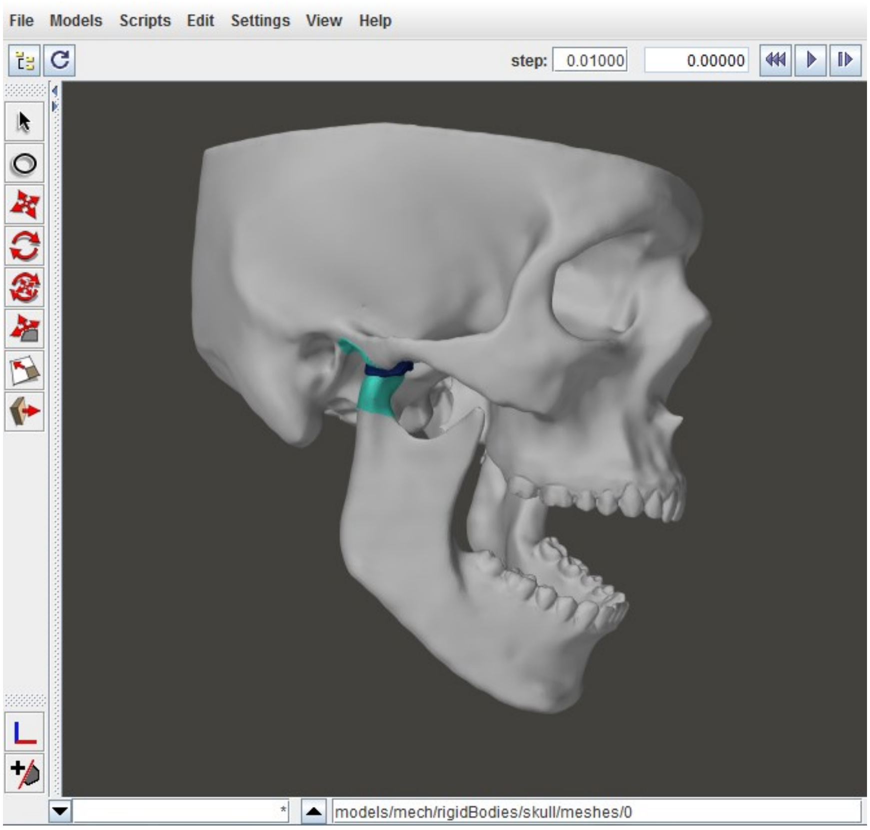

Figure 2: Model in opened mouth position loaded in ArtiSynth (cartilage in green; disc in blue)

3 RESULTS & DISCUSSION

Using the workflow described above we were able to successfully create models of all structures of the masticatory system for multiple static postures. Clear changes in disc positioning (Figure 3) and disc shape (Figure 4) are visible. Due to the three-dimensional visualization of the TMJ, and its changes for different functional movements, the presented model could also be a valuable tool in dental education.

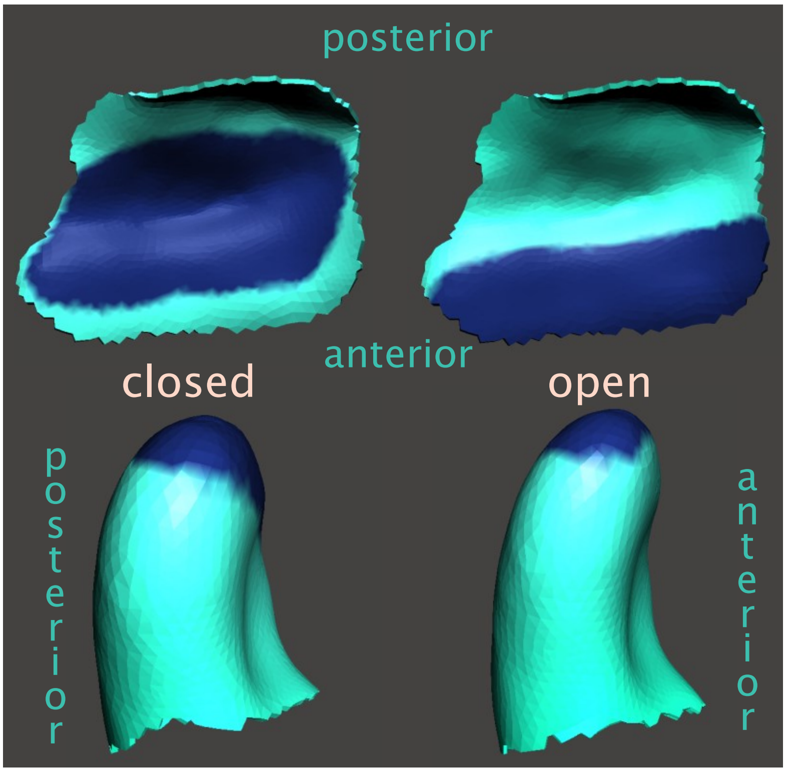

Figure 3: Position change of disc (dark blue area) in closed mouth (left) and opened mouth (right) position relative to skull from bottom-up view and relative to mandible in lateral view

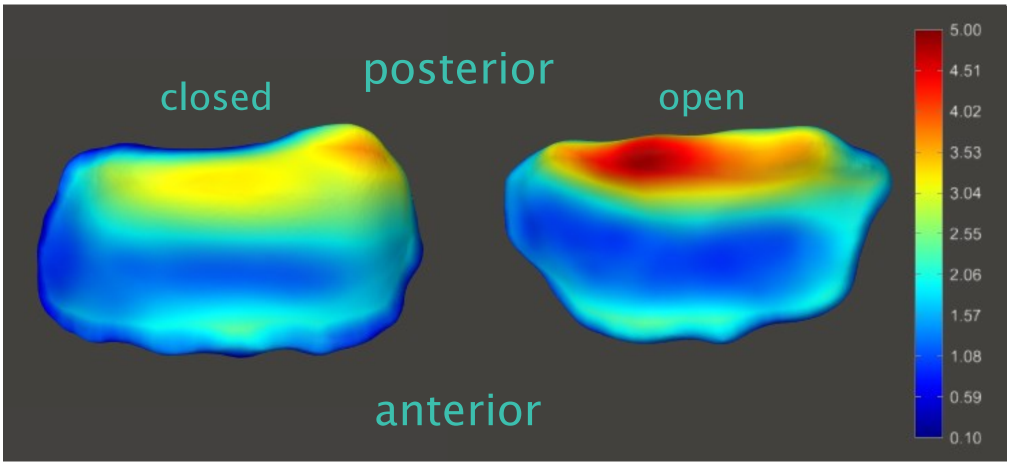

Figure 4: Thickness measurement of disc in closed mouth (left) and opened mouth (right) position from top-down view

In the future, this project aims to use the combined rigidbody/FEM model to gather insight into the mechanisms that underlie pathologies of the TMJ. Moreover, the model created for this project could potentially serve as a basis for studies that investigate the effects of different mandibular movement or muscle force patterns on the loading of TMJ structures.

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