Preprint of the paper which appeared in: THE XXX CONGRESS OF THE INTERNATIONAL SOCIETY OF BIOMECHANICS (ISB Congress 2025).

A Jaw Model Framework for the Development of an Exoskeleton to Treat Temporomandibular Disorders

Paul-Otto Müller[1] and Oskar von Stryk[1]
[1]Simulations, Systems Optimization and Robotics Group, Technical University of Darmstadt, Darmstadt, Germany
[1]Email: pmueller@sim.tu-darmstadt.de

Summary

Exoskeletons might provide an intriguing and effective opportunity to enhance and support the rehabilitation of temporomandibular disorders (TMDs) affecting the masticatory system. Three extendable and customizable jaw model variants, including a new approach to modeling the temporomandibular joints (TMJs), are presented to create the research basis and facilitate the design and prototyping of such a device. The code of the framework is publicly available on *GitHub* (https://github.com/paulotto/exosim).

Introduction

In recent years, significant advancements have been made in rehabilitative exoskeleton research, yet their application to TMD treatment remains limited. TMDs include various neuromuscular and musculoskeletal disorders that affect the masticatory system. Many of these conditions can be treated through physiotherapy, where an exoskeleton could potentially assist and gather data during the training process [1]. A robust jaw model is essential for developing such exoskeletons, which are rare in this field of research. Furthermore, while complex (finite-element) jaw models are well-documented in the literature, they are often closed-source. To address this, an open-source, customizable, and extensible framework featuring three distinct jaw models built on the simulator *Project Chrono* [2] is introduced as a foundation for researching jaw exoskeletons.

Methods

The jaw model (Figure 1a) consists of 24 configurable Hill-type muscles driving the masticatory system, eight ligaments modeled as inextensible cables to stabilize and restrict motion, and four rigid bones — the cranium, maxilla, mandible, and hyoid — with meshes sourced from public repositories [3]. The TMJs, among the most complex systems in the human body and connecting the mandible to the skull, are implemented in three variations, balancing accuracy and computational efficiency based on the use case. The first and fastest rigid-body variant constrains the mandibular condyles to a curved surface, reducing the degrees of freedom (DoFs) to five (Figure 1b). The second variant enables contact between the mandibular condyles and articular fossae, allowing the mandible's movements to be naturally constrained by the mesh geometries, resulting in a model with six DoFs (Figure 1b).

Although the first two models are sufficient for general jaw motion analysis, they overlook the complexity introduced by the elastic temporomandibular joint discs, which lie between the condyles and fossae, absorbing and distributing joint forces. To address this, the third variant incorporates TMJ discs as finite-element models connected by ligaments to surrounding bones (Figure 1b). While prior studies have included TMJ discs [4], a distinguishing feature of our model is the connection of the discs to the superior head of the lateral pterygoid muscles. This connection counteracts disc retraction when the mandible is closed and the condyles are shifted posteriorly. Although anatomically suggested, this feature is rarely implemented in jaw model literature.

The framework was developed using the *Project Chrono* simulator due to its open-source nature, active maintenance, support for FEM and multi-body physics, and compatibility with *C++* and *Python*.

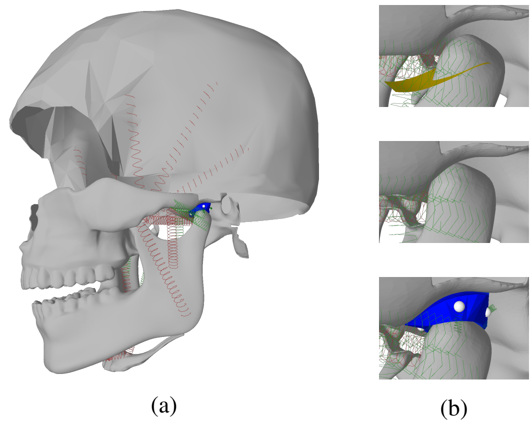

Figure 1: (a) Jaw model (red: muscles, green: ligaments, blue: TMJ disc, gray: bones). (b) The three model variants. Top: curved-surface constraint. Middle: mesh geometry constraint. Bottom: FEM discs.

Results and Discussion

The curved-surface variant operates in real-time, whereas the second and third models are approximately 40 and 1500 times slower than real-time, respectively. All model parameters and components can be easily modified via *JSON* files, enabling quick customization of the models for specific TMD patients without requiring advanced programming skills. Currently, model parameters are derived from the literature, and the FEM disc meshes are generated based on the imprints of the condyles and fossae. Moreover, such a jaw model provides the only practical approach to estimating forces within the TMJs, which is essential for evaluating and analyzing the impact of a jaw exoskeleton on the masticatory system. However, only qualitative insights into the joint conditions can be obtained at present, as no viable, non-invasive validation method is currently available.

Conclusions

An extendable and customizable framework comprising three jaw model variants has been introduced. These jaw models form the foundation for prototyping and studying the behavior of exoskeletons designed for TMD treatment, a field still in its early stages. The open-source nature of the framework is particularly beneficial, as it enables all researchers to work from a shared foundation, fostering collaboration and accelerating progress.

References

[1] Evans et al. (2016). *AMC*, 30-37.
[2] Tasora et al. (2015). *HPCSE*, 19-49.
[3] Hannam et al. (2008). *J. Biomech.*, **41**: 1069-1076.
[4] Sagl et al. (2019). *Front. Physiol.*, **10**: 1156.