Dynamic Hard-Soft Tissue Models for Orofacial Biomechanics

Ian Stavness,* John E. Lloyd, Sidney Fels
University of British Columbia

Yohan Payan
TIMC-IMAG Lab, CNRS, France

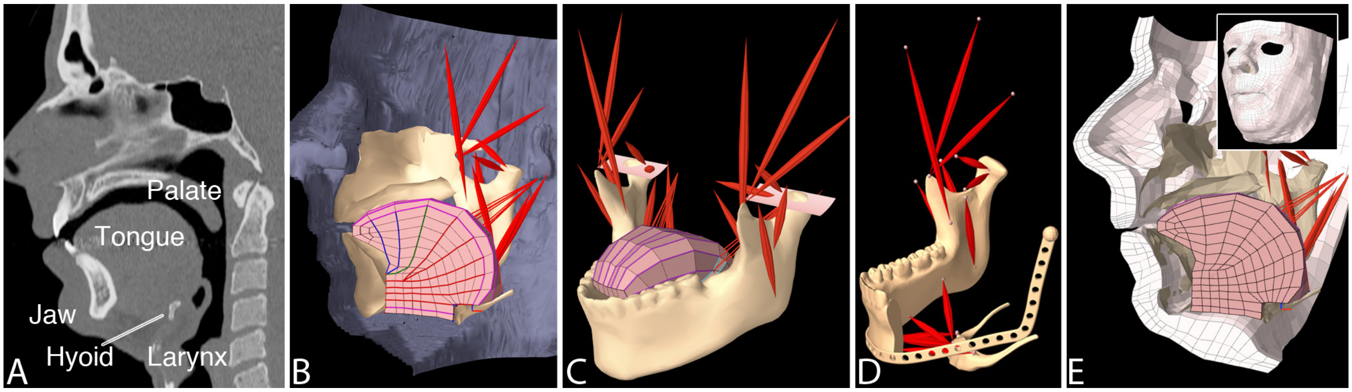

Figure 1: *CT image data (A) is used to adapt a reference model to a subject (B). Model components include rigid bony structures (jaw, maxilla, hyoid bone), a deformable tongue model, and point-to-point Hill-type muscles (C). Alterations that mimic surgical procedures (D) can be used to assess post-operative outcomes and deficits. We are coupling the jaw-tongue-hyoid model to a deformable face model (E).*

1 Introduction

Dynamic modeling of muscle-driven anatomical structures provides a means to better understand complex biomechanical systems. A rich application area for such models is the human orofacial anatomy, shown in Figure 1A, which is involved in a wide range of important functions including chewing, swallowing, breathing, and speaking. Comprehensive models of orofacial biomechanics will enhance our limited understanding of dysfunctions such as obstructive sleep apnea, swallowing disorders, and post-surgical deficits, such as reconstructive jaw surgery (Figure 1D).

Orofacial anatomy is particularly challenging to model as it is composed of an intricate arrangement of rigid structures including the skull, jaw, and hyoid bone as well as highly deformable muscle-activated tissues such as the tongue, lips, soft palate, pharynx, and larynx. Orofacial function involves the coordination of many muscles that can exert large forces, generate fast movements (up to 80 cm/s in speech), and create extensive contact between structures. In this talk, we present work which uses recent medical imaging segmentation and registration techniques together with coupled hard/soft tissue simulation, to create a first-of-its-kind model of jaw-tongue-hyoid biomechanics.

2 Approach

Combining medical image data and reference models Our coupled jaw-tongue-hyoid model (Figure 1B,C) is based on two previous isolated biomechanical models: a multi-body model of the jaw and hyoid [Hannam et al. 2008] and an FEM tongue model [Buchaillard et al. 2009]. Starting from these, we adapted their skeletal and muscle geometry, with a non-elastic mesh-based registration algorithm [Bucki et al. 2010], to fit CT data[1] for a specific subject (Figure 1A,B). After registration, the models were coupled together by attaching FEM nodes of the tongue model to locations on the jaw and hyoid rigid-bodies, allowing the tongue and its muscles to act on the surrounding bone structures, and vice versa.

Dynamic simulation method Dynamic model simulation is done using ArtiSynth (www.artisynth.org), an open-source Java-based biomechanical modeling toolkit that provides graphical model editing and simulation control and fast computation times. ArtiSynth uses a semi-implicit integrator based on a mixed linear complementarity formulation to solve the combined dynamics of particles, rigid bodies, linear or nonlinear FEMs, and bilateral and unilateral constraints including contact. Attachments between different model components are effected using point-based constraints. These constraints can also be used to add marker points to rigid bodies or FEM elements for purposes such as attaching muscles or tracing motions. Muscle activation is achieved using point-to-point force effectors that can implement a variety of muscle types, including those based on the Hill model. Muscle activated tissue can be modeled by embedding these force effectors within an FEM model. Our tongue model uses hexahedral elements and a nearly-incompressible Mooney-Rivlin type material.

Results and future directions We simulated a number of tasks, including unilateral chewing and tongue motions used in speech production, to test the model and evaluate the importance of jaw-tongue coupling. The results were consistent with literature data and also showed that coupling is indeed important; in particular, the presence of passive tongue tissue between the jaw and hyoid appears to significantly resist jaw movement. Simulation times were also much faster compared to commercial packages: 100 ms tasks could be computed within 10 seconds, compared with the 40 minutes required for the tongue model alone as reported in [Buchaillard et al. 2009]. We are currently coupling the jaw-tongue-hyoid model to a deformable face model (Figure 1E) and have created preliminary simulations of integrated orofacial biomechanics.

Hannam, A., Stavness, I., Lloyd, J., and Fels, S. 2008. "A dynamic model of jaw and hyoid biomechanics ... chewing". *J Biomech 41*, 5, 1069–1076.

Buchaillard, S., Perrier, P., and Payan, Y. 2009. "A biomechanical model of cardinal vowel production ... ". *J Acoust Soc Am 126*, 4, 2033–2051.

Bucki, M., Nazari, M., and Payan, Y. 2010. "Finite element speaker-specific face model for ... speech production". *Comput Methods Biomed, in press.*

*e-mail: stavness@ece.ubc.ca

[1] CT data provided by P. Badin at Gipsa-Lab

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