Towards jaw-tongue coupling for speech: modeling the jaw with a soft body approach

Florian Vogt, Stéphanie Isabelle Buchaillard, Mohammad Ali Nazari, Pascal Perrier, Yohan Payan

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Florian Vogt, Stephanie Buchaillard, Mohammad A. Nazari, Pascal Perrier
ICP/GIPSA Lab,UMR CNRS 5216
Grenoble INP, France
florian.vogt@gipsa-lab.grenoble-inp.fr

Yohan Payan
TIMC-IMAG, UMR CNRS 5525
Université Joseph Fourier
Grenoble, France

Abstract

The jaw plays a significant role in speech production. This work introduces a muscle activated dynamic jaw model that will be connected in the future to the 3D tongue model already developed by our group. The bone structure of the jaw, extracted from CT Images, is represented as a biomechanical model using quadrilateral shell elements. Opener and closer muscles are represented as line-segmented link elements. The temporomandibular joint constraints are defined as nodal limits. The combined bone, muscle, and joint model is simulated in the ANSYS software package.

Keywords: Dynamic jaw modeling, finite shell elements, ANSYS simulation, and biomechanical modeling.

1. Introduction

The preliminary dynamics jaw model is aimed to study speech production in combination with the biomechanical finite element tongue-hyoid model developed by Buchaillard and colleagues [1, 2]. Towards a combined tongue-jaw model, we choose a soft body framework to formulate the jaw to represent the jaw in the ANSYS finite element modeling package and may enable later study of jaw stresses. Jaw deformation is not relevant for speech studies but can be meaningful for clinical applications. In speech, forces on the jaw are small, compared to mastication, while stiffness of jaw bone is much higher than the one of tongue tissues; consequently the deformation of the jaw is not anticipated to have a first order effect on tongue-jaw motion. This work was motivated by the initial tongue-jaw model presented in [3] using a rigid jaw/finite element formulation, which was found to show instabilities. These instabilities are an engineering challenge that was solved by [4] using a rigid body/finite element connection formulation. Our approach is to formulate the jaw and tongue in a unified finite element framework. The jaw-tongue coupling is of particular relevance in speech production and for understanding of speech, according to [5] and [6].

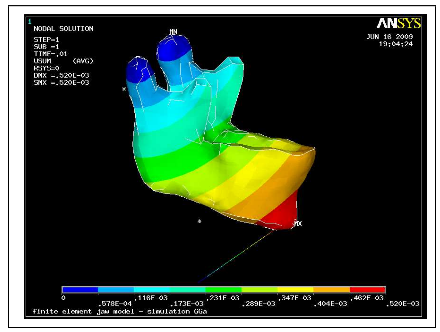

Figure 1. Dynamic jaw simulation for opening in ANSYS with displacement field coloring.

2. Model formulation

The dynamic jaw model consists of three components realized in the ANSYS finite element framework: a finite element jaw, point-to-point opener and closer muscles and a temporomandibular joint formulation.

In order to obtain subject specific shapes, anatomical hard structures of the head are extracted as a mesh from computed tomography images (1x1x4mm resolution) of a male subject. This enables to create both a jaw mesh formulation, as well as, to extract skull and hyoid meshes to determine muscle insertions of the jaw. The predominant quadrilateral jaw mesh consists of 1390 elements, which were slightly modified from the version presented by [1]. The finite element jaw model, shown in Figure 1, is based on four-node thin shell elements (shell63) with 5mm thickness, which produces a smaller and faster system than volumetric hexahedral or tetrahedral alternatives. The finite element shells have a 2000 kg/m^3 density, 0.3 Poisson's ratio, and $9.6MPa$ Young's modulus which is consistent with published data by [7] and [8].

The configurations and placement of opener and closer muscles are consistent with the dynamic jaw model presented by [9] as point to point muscles. The muscles are formulated as cable elements (link10) and allow the indirect force activation based on element strain.

Lastly, the temporomandibular joint constraints are implemented as two translational node limits of surface nodes at the condyle. This approach simplifies the joint as a hinge and ignores sliding motion on the s-shaped joint behavior of the mandibular fossa and articular disc.

The coupling between hyperelastic tongue and thin shell jaw model is currently in progress and the first results will be presented during the conference.

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