A 3D biomechanical tongue modelto simulate speech movements

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Introduction

This paper introduces a 3D biomechanical dynamical model of the human tongue. The model is designed to be used to study the speech production process, and more specifically the motor control of the human tongue, from muscles activity patterns to tongue movements. Tissue elastic properties are accounted for in Finite Element Method (FEM). The FEM mesh was designed in order to facilitate the implementation of muscle arrangement within the tongue, based on accurate anatomical data. Muscles are modelled as functional force generators that act on anatomically specified sets of nodes of the FEM structure. The model and the solving of the equations of movement are implemented using the ANSYS™ software.

Methods

The design of the mesh, based on the Visible Human dataset, was guided by the requirement to build up a 3D geometrical structure that could match the muscle morphology within the tongue as closely as possible (Wilhems-Tricarico, 2000). Time dependence of shapes being important in speech production, our model was designed in a dynamic framework. Napadow and colleagues (1999) reported tongue tissue deformations as large as 200% for elongation and 160% for contraction. Consequently, a small deformation framework is not adequate. Therefore, our 3D model was developed in the large deformation framework.

To our knowledge, no constitutive law has been provided for the human tongue tissues. Since cardiac muscles, with their interwoven fibers and their characteristics of fast muscles, present a number of similarities with tongue muscles, the constitutive law of myocardium muscles (Taber and Perucchio, 2000) was chosen. According to Fung (1993), an exponential hyperelastic energy function would be particularly well adapted for biological soft tissues. Consequently, Taber and Perucchio's (2000) exponential law for the myocardium seemed adequate to us and was implemented in the model (figure 1).

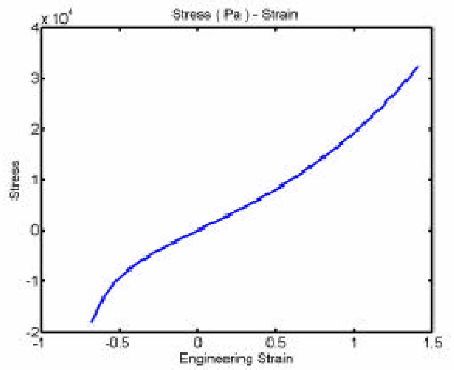

Fig 1: Stress-strain relationship

Results

Simulations were computed with a 120ms muscle contraction pattern, from rest to maximal activation. Figure 2 plots two simulations resulting from Superior Longitudinalis and Styloglossus muscles activations. The sets of elements associated with the recruited muscle are represented in dark gray, the tongue mesh at rest (without gravity) is plotted in light gray, and the final tongue shape obtained after muscle activation is represented in white.

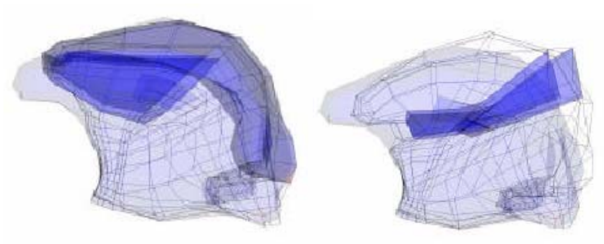

Fig. 2: Superior Longitudinalis with 1N force (left) and Styloglossus with 3N force (right)

Discussion and Conclusion

A 3D biomechanical model of the human tongue has been developed, in order to test and improve speech motor control models. In its current state, the model is not embedded in a 3D description of the vocal tract. Preliminary simulations of the impact of tongue muscles activation were evaluated. They show that the main directions of deformation are in agreement with experimental data about speech production. However, some aspects of the modelled deformation do not conform with actual tongue shapes observed during speech. A more extensive evaluation will be made in the 3D space, using in particular MRI data.

References

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