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Predicting the consequences of tongue cancer surgery: design of a 3D patient-specific biomechanical model and evaluation

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1 Introduction

The preoperative prediction of the consequences of tongue cancer surgery on tongue mobility is a topic of paramount interest for maxillo-facial surgeons. Loss of tongue mobility is associated with an impairment of basic functions such as speech articulation and deglutition which can, in some cases, induce a substantial decrease in the quality of life of patients [1]. Significant variability has been observed across patients in the recovery of these functions, which are linked with tumor location and reconstruction techniques, but also, strongly, with patient-specific characteristics, such as vocal-tract morphology and idiosyncratic motor control strategies and which call for the development of tools to predict the functional consequences of tongue cancer surgery.

Recent advances in our group on the development of a three-dimensional (3D) finite-element biomechanical model of the oral cavity [2, 3] and on the design of automatic adaptation of finite-element meshes to subject-specific morphology [4] constitute encouraging steps towards the development of pre-operative planning tongue surgery systems. In particular, Buchaillard et al. [5] showed the potential of such models to qualitatively predict the impact of oral cancer ablative surgery and reconstruction on tongue mobility. Building upon this work, our objective is to perform a clinical evaluation of the proposed biomechanical model by comparing between the acoustic signal predicted by our model after tongue cancer surgery and the acoustic data collected in post-surgery conditions. In the present work, we focus on the design of a 3D patient-specific biomechanical model.

2 Materials and methods

2.1 Materials

Pre-operative Magnetic Resonance Images are acquired on the head of a 50 year old patient undergoing tongue cancer using a 3-T clinical scanner and pixel resolution 1 x 1 x 1 mm^3. Acoustic data of the patient in both pre-surgery and post-surgery conditions were also collected following the procedure developped by Acher et al. [6].

2.2 Methods

An improved version of the 3D Finite Element (FE) model of the oral cavity developed in ANSYS at the laboratory [3] is used. It consists of a soft deformable tongue and the surrounding hard tissues with which the tongue interacts (jaw, teeth, palate and hyoid bone). The improvements relate, primarily, with the tongue mesh as described in [7]. The identification of each muscle group in the tongue mesh is performed

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automatically. Muscle activation is modelled using the FE formulation of the Hill muscle model proposed by Blemker et al. [8, 9] that includes both the active stress stiffening effect and the passive transversal isotropy of muscles. Passive tissues (inactive muscles) are modelled using a 5-parameter Mooney-Rivlin model.

The patient-specific model is automatically set up using pre-operative MR data coming from a patient undergoing tongue cancer surgery. A volume image registration-based approach is used, in which an atlas FE mesh is deformed using a 3D transform derived from patient-to-atlas volume (MR) image registration [10]. The volume image registration includes rigid/affine registration (as global alignment) and non-rigid registration (as local alignment). The global transformation removes the scale and position differences between the atlas and patient (MR) image volumes. Accordingly, the local transformation compensates the inter-patient morphological differences. Finally, the obtained 3D deformation field (derived from registration) is used to deform the tongue atlas mesh to fit the patient's tongue morphology. As the deformed mesh may possess irregular or low quality elements, an automatic mesh repair algorithm is used [4].

Tongue cancer surgery was accounted for in the model by modifying the biomechanical properties of the tongue tissues that were excised and reconstructed during the surgical procedure. This was done in collaboration with a maxillo-facial surgeon. First, the zone that was resected was identified and the corresponding elements in the biomechanical model were removed. In our case, the hemi-glossectomy performed by the surgeon consisted in resecting partially or totally the styloglossus, the tranversalis, the hyoglossus and the genio-glossus muscles. Then, the tongue model was reconstructed with flaps having passive elastic properties. In practice, the surgeon used an anterolateral thigh cutaneaous flap. The flap is totally inactive during tongue activation.

The response of the tongue to the activation of muscles, responsible for the production of cardinal vowels /i/, /a/, /u/, after tongue surgery, is simulated. The deformed tongue surface is then used as input for the acoustic model of sound synthesis which, in turn, is used to compute the predicted spectral characteristics of vowels in post-surgery condition.

3 Results

The patient-specific tongue geometry and mesh reconstructed from the Pre-operative Magnetic Resonance Images is represented in figure 1 below.

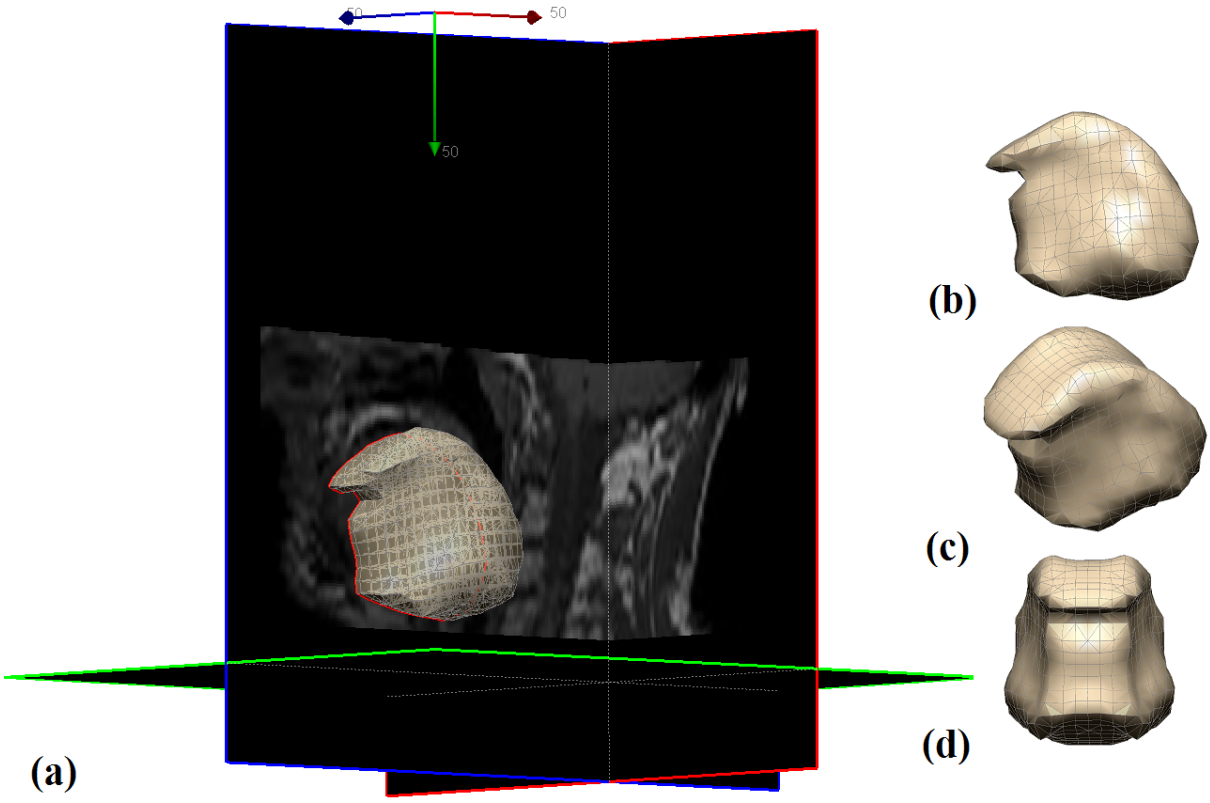

Figure 1: (a) Pre-operative MR data of the patient undergoing tongue cancer surgery superimposed with the 3D patient-specific tongue mesh set-up. (b) Side, (c) isometric and (d) front views respectively of the 3D FE tongue mesh.

4 Perspectives

Comparison between the acoustic signal predicted by our model and the acoustic data collected in post-surgery conditions (6 months after surgery) is currently being performed and will serve as basis for the evaluation of the prediction of the impact of the surgery.

5 Conclusion

A patient-specific biomechanical model is set up in this study to predict the impact of surgery on tongue mobility. Evaluation of the model is done by comparing the simulated acoustic signal with the acoustic data collected in both pre-surgery and post-surgery conditions. Further work is required to (i) develop appropriate numerical strategies that allow to accurately handle and account for the resection and reconstruction procedure and (ii) reduce computation time.

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