CSMA 2017
13ème Colloque National en Calcul des Structures
15-19 mai 2017, Presqu'île de Giens (Var)

Subject-Specific Modeling of Facial Mimics derived from MRI Data using FEM

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Resume — A muscle-driven model of human lower face was established. Three pairs of facial mimic muscles (ZM - Zygomaticus Major, LLS - Levator Labii Superioris, LAO - Levator Anguli Oris), subcutaneous soft tissues, skin and skull were reconstructed based on segmentation of subject-specific MRI data. FE simulation were performed to reproduce designed facial mimic positions (e.g. pronunciation of sound /o/), with comparison to experimental measurements. Muscle was modeled as a transversely-isotropic hyperelastic material with autonomous contraction.
Key words — facial mimic, subject-specific, FEM (Finite Element Method), MRI.

1. Introduction

Face plays an important role in interpersonal communication. In case of facial traumas or pathologies, surgical treatment is often necessitated. In the post-operative stage, evaluation of treatment quality is of utmost importance to guide functional rehabilitation for the patient. However, current criteria (visual observation and palpation) are too subjective; more objective and quantitative criteria are demanded. In this context, we propose to reconstruct subject-specific geometry of human face and to perform numerical simulation qualified by experimental measurements, thus getting further understanding of intrinsic mechanism of facial mimics. To be noted that the leading role in facial mimics – facial mimic muscles were modeled with a transversely-isotropic hyperelastic behavior law in order to simulate its fiber-reinforced like mechanical properties.

2. Methodology

2.1. Segmentation of MRI data and geometric modeling

MRI data of lower head of a healthy subject were acquired [1]. The segmentation of muscles of expression was performed manually by an experienced clinician. The segmentation of soft tissues and skull were performed semi-automatically. All segmentation was performed using ScanIP (Simpleware©, UK). Geometric modeling for muscle, soft tissue, and skull was established individually using home-made process [1, 2].

2.2. Numeric (FE) modeling

For the material assignment, a transversely-isotropic, hyperelastic, quasi-incompressible behavior law [3] was implemented for facial muscles. Relevant information, such as muscular contraction amplitude and fiber direction was defined according to MRI measurements. A hyperelastic behavior law using a second-order reduced polynomial constitutive model [4] was assigned to subcutaneous soft tissues for possible large deformation. Skin envelop was model as linear elastic material [5]. Origination end of muscle and bottom of head (soft tissues volume) were fixed as boundary conditions. The interaction between muscle and surrounding soft tissues was defined as tie constraint. All the simulations were performed using Abaqus/Explicit solver v6.12-3 (Dassault Systèmes©, France).

3. Results and Discussion

3.1. Geometrical model

Results of geometric modeling based on segmentation of MRI images are shown in Figure 1.

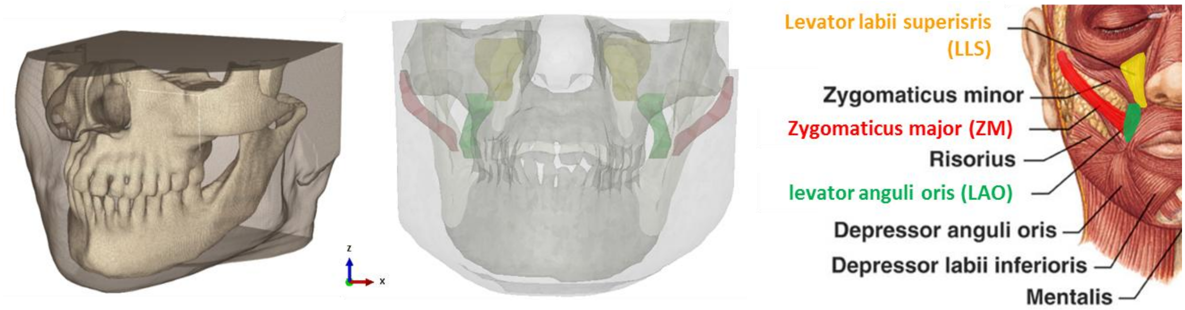

Figure 1 – (left) soft tissues and skull; (middle) reconstructed muscles: zygomaticus major (ZM) in red color, levator labii superioris (LLS) in yellow color, levator anguli oris (LAO) in green color; (right) anatomical chart showing the relative position of reconstructed muscles.

3.2. Meshed model

The geometric model was meshed with tetrahedral elements in Abaqus CAE 6.12-3 (Dassault Systèmes©, France). Meshed geometry is shown in Figure 2. The number of elements for different part of geometry are summed up in Table 1.

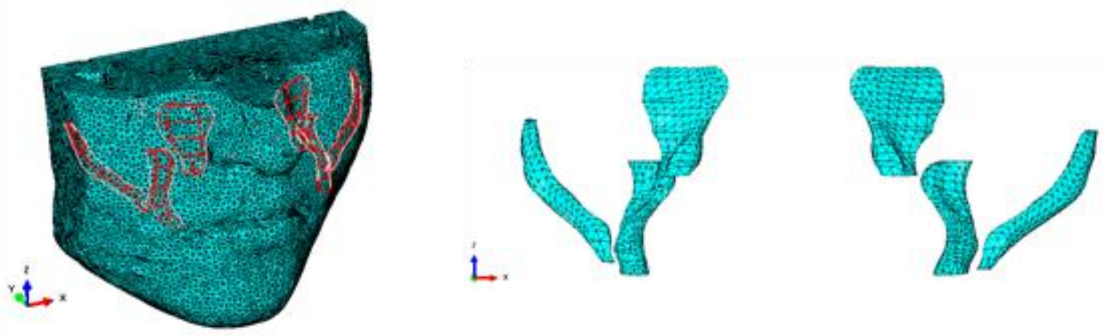

Figure 2 – Meshed model

Table 1 – Number of elements for different part of geometry in the face model

	Soft tissues	Skin shell	Right ZM	Left ZM	Right LLS	Left LLS	Right LAO	Left LAO
Number of elements	458973	15633	948	957	1064	1058	1502	1513

3.3. Numerical simulations using FEM

A series of simulations were performed for the mimic position – pronunciation of sound /o/, with different pair(s) of mimic muscles involved, as shown in Figure 3. The plotted physical quantity is node displacement magnitude (U in mm) of the FE model.

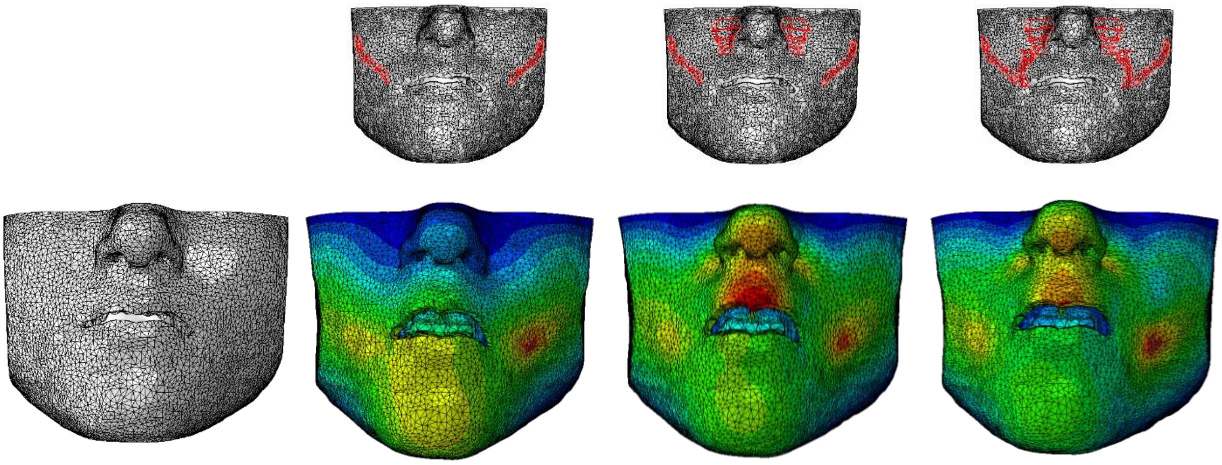

Figure 3 – Simulation of pronunciation of sound /o/ with different pairs of mimic muscles involved: (from left to right) neutral position; ZM involved; ZM+LLS involved; ZM+LLS+LAO involved.

3.4. MRI-based experimental measurements

For the mimic position - pronunciation of sound /o/, the displacement of skin was measured experimentally as an average of representative points on face model derived from MRI data, as shown in Figure 4.

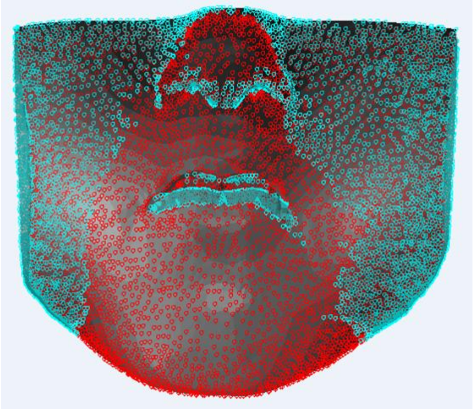

Figure 4 – MRI-based experimental measurements of the displacement of skin (neutral position in blue and final position for pronunciation of sound /o/ in red)

3.5. Comparison of numerical and experimental results

Numeric simulation results are compared with experimental measurements in Table 2. The compared physical quantity is displacement magnitude (U in mm) of facial skin from neutral position to final deformed position in the pronunciation of sound /o/. It is observed that the simulation result gets increased toward the experimental measurement as more pairs of relevant facial mimic muscles involved in the simulation, and finally the relative difference between simulation and experimental measurement is 15% with three pairs of muscles (ZM+LLS+LAO) involved in the simulation. However, a special decrease occurred when muscle LLS was added in the simulation (*). This fact is possibly due to the special role of LLS plays in this facial mimic position: LLS lifts the upper lip whereas the global deformation extent on face is decreased as a result.

Table 2 – FE simulation results vs. MRI-based experimental measurements

U (mm)	FE simulation			MRI measurement
	ZM	ZM+LLS	ZM+LLS+LAO	
Facial skin	3.3±2.2	2.6±2.4*	4.5±2.0	5.3±3.4

4. Conclusions and Perspectives

Simulation of facial mimics have been accomplished with our subject-specific FE model of lower face derived from medical imaging data, with three pairs of facial mimic muscles (ZM+LLS+LAO) involved. This work corroborates the feasibility of a subject-specific image-based and muscle-driven face model to reproduce facial mimics through numeric simulations. By comparison with experimental measurements, it is shown that the involvement of more relevant muscles indeed improve the simulation results. In future work, the model will be completed by adding more muscles. Moreover, subject-specific data on material properties of biological tissues are planned to be acquired through experiments, in expectation of increasing the bio-fidelity of this subject-specific model.

5. Acknowledgements

This work was carried out in the framework of the Equipex FIGURES supported by the French Government, through the program "Investments for the future" managed by the National Agency for Research (ANR-10-EQPX-01-01). Contributions of CHU Amiens are gratefully acknowledged.

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