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Facial Mimics Simulation using MRI and Finite Element Analysis*

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Abstract—**Recent research studies aimed to simulate facial expressions or motions due to muscle contraction using biomechanical models ranging from basic to advanced muscle constitutive models. However, these models are based on generic geometries and there is a lack of experimental data for the numerical simulation as well as for the model validation in a clinical context. The objective of our present study was to perform facial mimics simulation using subject specific data derived from MRI technique. Zygomaticus major muscle is modelled as a transversely isotropic hyperelastic material. Then the resulting effect of its shortening and lengthening process on the facial mimics simulation was performed using Finite Element Analysis. Simulation results were presented and discussed. Such study will be of interest for defining objective criteria to evaluate the facial disfigurement patients and to perform the functional rehabilitation.**

I. INTRODUCTION

Comprehension of facial mimics mechanism is of great interest in clinical rehabilitation treatment of facial disfigurement patients. At the present time, the evaluation of facial mimics has been based only on the subjective palpation and observations of the clinicians leading to inappropriate treatment prescription. Numerical simulation could be used to provide more intrinsic internal information of the facial muscle contraction and coordination mechanism for a more objective evaluation [1]. Rigid-body biomechanical models have been used to study the mechanical behavior of facial motions such as mastication with temporomandibular joint [2]-[4]. However, this modeling approach cannot simulate accurately the muscle behavior due to modeling limitations and assumptions [5]. Biomechanics deformable model is alternative solution to improve the accuracy of the numerical simulation. Some studies aimed to simulate facial expressions or motions due to muscle contraction using biomechanical advanced muscle constitutive models [6]-[9]. However, these models are based on generic geometries and there is a lack of objective data for the simulation set up as well as for the model evaluation in clinical context.

Medical imaging such as MRI or CT becomes customized research technique to acquire individualized anatomical geometries and mechanical properties of biological tissues for developing musculoskeletal models such as finite element (FE) model or rigid multi-body dynamics model [1], [10]-[11]. Advanced segmentation and reconstruction methods from typical commercial tools (Simpleware, Amira, Mimics) have been applied on anatomical slide-by-slide images to extract surface-based interest structures. STL format has been selected as customized exchanging standard with other CAD software. In addition, mesh generation has to be performed for finite elements analysis. However, use of STL-based surface to perform meshing showed technical disadvantages such as limited type of elements and inflexible mesh modifications leading to bad quality of mesh and convergence problem

The objective of our present study was to perform facial mimics simulation using subject specific data derived from MRI technique. For this purpose, a geometrical transformation procedure was also developed to generate point clouds data from image-based STL surface model. Consequently, this will be of help for generating the mesh of the different structures for FE analysis. Moreover, point clouds data can be easily used for adaptive mesh refinement purpose.

II. MATERIALS AND METHODS

A. MRI Data Acquisition

A muscle-specific 3Tesla MRI protocol (3DFSPGR Sagittal T1 sequence, FOV=24x24mm², slice thickness = 1.6mm, acquisition time = 7 seconds) was developed at the CHU Amiens to acquire anatomical images of the facial soft tissues (fat and skin) and the zygomaticus major (ZM) muscle at 4 different positions (neutral, smile, pronunciation of sound "O", pronunciation of sound "Pou") of a healthy subject (female, 24 yo, 1.5 m, 57 kg).

B. Segmentation and Reconstruction

The ZM muscle tissue was segmented using manual segmentation with the ScanIP module (Simpleware, UK) (Fig. 1). Other facial soft tissues (fat and skin) were segmented using semi-automatic segmentation. Due to the complexity of the facial soft tissue morphologies, an experienced clinician performed these segmentations to ensure each segmented pixel belongs to the related facial soft tissues. Then, marching cube algorithm was used to reconstruct the 3D geometries of the face and ZM muscle models. The result was saved in STL format for further processing.

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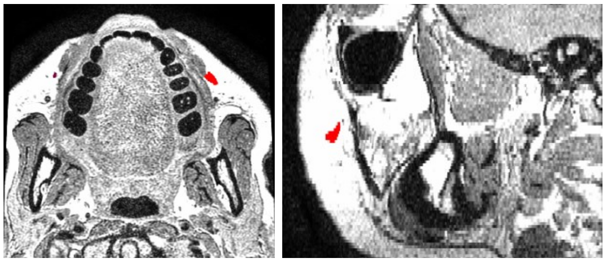
(A) (B)

Figure 1. Segmented MRI images of the left ZM muscle (in red color): axial (A) and Sagittal (B) planes

C. *Meshing*

From STL-based surface models of the face and ZM muscles, a specific geometrical transformation procedure was developed using VTK (Kitware Inc., USA) and Python (PSF, USA) to extract their point clouds. The algorithm was expressed as follows:

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Point clouds slicing extraction algorithm
Input: STL-based surface model
Output: point clouds data
Begin
(1) Read surface model from STL file
(2) Get surface boundary
(3) Define the number of planes (N-Planes) and the number of points per plane (N-Points)
(4) Define the normal of slicing plane
(5) For each plane until N-Planes are reached
    (i) Get intersection between surface boundary and the current plane
    (ii) Extract feature edges and points
(6) Realign all points of N-Planes along the normal
(7) Write extracted point clouds data in text data file
End.
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B-spline algorithm was applied to develop contours from point clouds data using PATRAN 2005 and then mesh was generated by using Abaqus 6.9 CAE.

D. *Finite Element Simulations of Facial Mimics*

The simulations of 3 facial motions (Smile, “O” sound, and “Pou” sound) resulting from ZM muscle contraction were performed using the FEBio code [12]. Meshed models of the facial fat and skin tissues (15591 nodes and 56981 tetrahedral elements) and ZM muscle (379 nodes and 1178 tetrahedral elements) were imported in PreView 1.4 software (Musculoskeletal Research Laboratories (MRL), University of Utah, USA) to specify the boundary conditions and material properties. The ZM muscle is modelled as a transversely isotropic hyperelastic material (full activation level, muscle along-fiber orientation with constant value). All muscle model parameters were set up as default values. Other soft tissues such as skin and fat layer were modelled as one-layer isotropic and hyperelastic material using Mooney-Rivlin mechanical law (C_1 = 2.5e-3 MPa and C_2 = 1.175e-3 MPa) [9]. Appropriate boundary conditions were applied. Zygomaticus major proximal attachment extremity was fixed to the face bone; the face was fixed in superior and inferior sides; and the displacement was prescribed at the distal muscle insertion point. The numerical results were confronted with MRI-based results to evaluate the zygomaticus major muscle contraction behavior. Subject specific facial mimics motions were simulated with displacement resulted from zygomaticus major muscle at the distal muscle insertion point. Post-processing was performed with PostView 1.3 software (MRL, University of Utah, USA).

III. RESULTS

3D geometrical models of the face and ZM muscles are illustrated in Fig. 2.

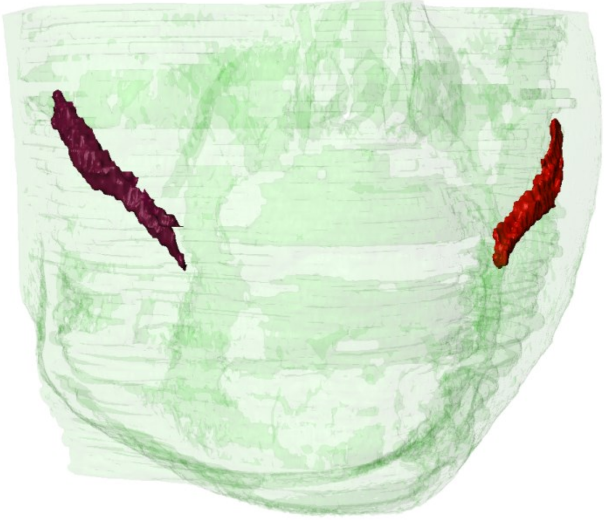

Figure 2. Reconstructed 3D STL-based surface models of face and ZM muscles (left and right sides)

Solid and meshed model of the ZM muscle are shown in Fig. 3.

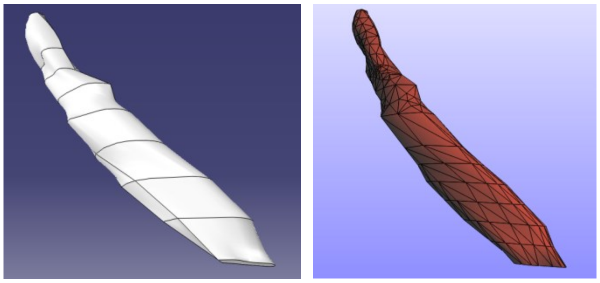
(A) (B)

Figure 3. Illustration of smoothed solid (A) and meshed (B) models of the ZM muscle

The lengthening process of the zygomaticus major muscle to perform the pronunciation of sound “Pou” is illustrated in Fig. 4. The FE simulations of zygomaticus major (ZM) for 2 other positions (smile and “O”) are presented in Fig. 5 and Fig. 6. Maximal absolute and relative displacement deviations of the extreme points between FE simulation and MRI-based results are summarized in Table 1. The maximal absolute deviation is ranging from 0.87 mm to 1.94 mm for all simulated positions. Moreover, as compared to MRI-based data for 3 positions, good agreement was founded for "Pou" (ΔL_{Pou_MRI}=5.39 mm and ΔL_{Pou_SIM}=6.34 mm) and "O" (ΔL_{O_MRI}=12.43 mm and ΔL_{O_SIM}=13.5 mm) positions. The "Smile" position shows a lack of shortening contraction (ΔL_{Smile_MRI}=-3.53 mm and ΔL_{Smile_SIM}=-7.88 mm) despite a good qualitative comparison. The FE simulations of face motions for 3 positions (smile, "O" and "Pou") were presented in Fig. 7.

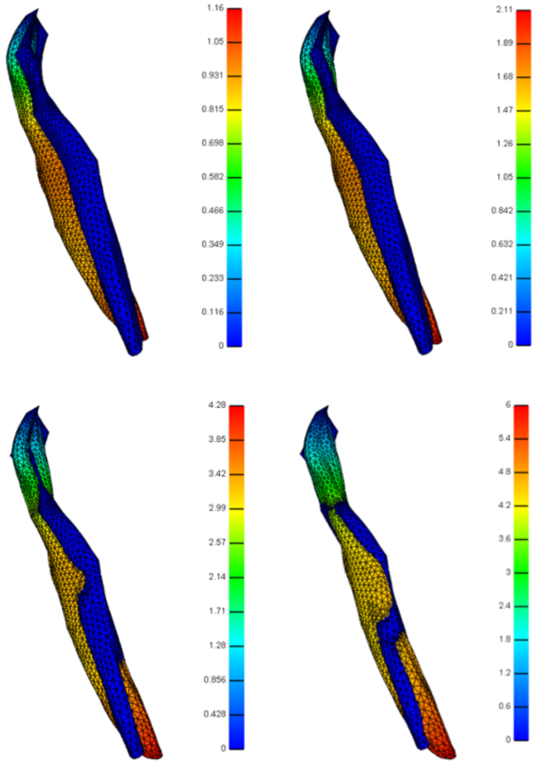

Figure 4. ZM muscle lengthening (from left to right and from up to down) during the pronunciation of sound "Pou": the final MRI-based geometry of the ZM muscle is in blue color; color map represents the displacement map (in mm) of simulated model according to its initial position

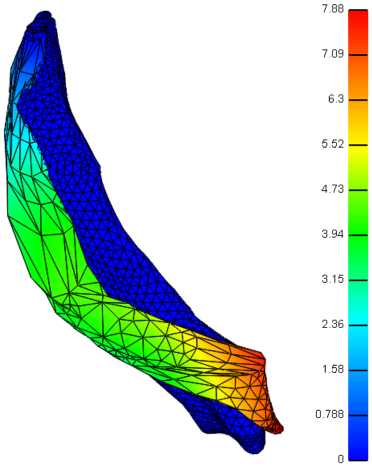

Figure 5. Illustration of zygomaticus major simulated for "smile" position: the final MRI-based geometry of the ZM muscle is in blue color; color map represents the displacement map (in mm) of simulated model according to its initial position

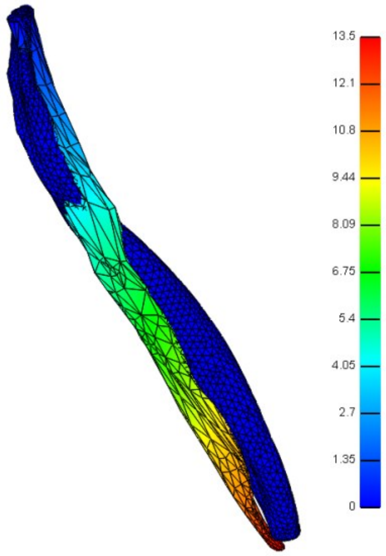

Figure 6. Illustration of zygomaticus major simulated for "O" position: the final MRI-based geometry of the ZM muscle is in blue color; color map represents the displacement map (in mm) of simulated model according to its initial position

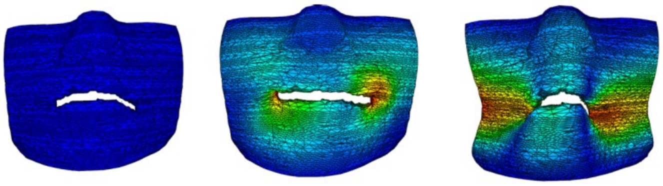

Figure 7. Facial simulation at 3 positions: neutral (left), smile (middle) and "Pou" (right)

TABLE I. MAXIMAL ABSOLUTE AND RELATIVE DISPLACEMENT DEVIATIONS OF FE SIMULATIONS CONFRONTED TO MRI-BASED RESULTS

Smile		"Pou"		"O"	
Absolute (mm)	Relative $\Delta D/D_{MRI}$ (%)	*Absolute (mm)*	*Relative $\Delta D/D_{MRI}$ (%)*	*Absolute (mm)*	*Relative $\Delta D/D_{MRI}$ (%)*
0.87	12.41	1.35	17.55	1.94	16.78

IV. DISCUSSION

Medical imaging allows subject specific or patient specific geometries to be acquired. However, these image-based geometries showed irregular defects for complex and small tissues such as facial muscle or cartilage models [13]. Thanks to our specific procedure, image-based surface model is smoothed and then, related mesh can be generated in a flexible manner. In fact, the number of elements can be reduced leading to reduce computing time. In addition, modifications can be done directly during mesh generation process to adapt to a specific simulation purpose such as FE analysis of facial mimics.

Concerning our numerical simulation, for the first time, MRI-based data of the muscle geometry were integrated into a FE model to simulate facial mimics. Moreover, MRI-based experimental data were used to evaluate the FE simulation results of facial muscle mechanism. The FE simulations showed best quantitative and qualitative results for “O” and “Pou” positions. However, the “Smile” position shows a lack of contraction despite a good qualitative comparison.

Advanced muscle constitutive models have been used for biomechanical analysis [6]-[9], [14]-[19] as well as for computer simulation and animation [20]-[21]. Muscle was commonly modeled as a transversely isotropic hyperelastic material. These studies showed that this material is appropriate for describing the skeletal muscle behavior. However, experimental data need to be acquired in a subject specific manner to improve the bio-fidelity of numerical model. For the geometrical properties, medical imaging becomes customized technique to acquire specific geometries of the subject under investigation. However, other intrinsic properties such as muscle mechanical and activation properties are commonly set up using experience-based hypotheses or under numerical convergence requirement. Consequently, new effort needs to be investigated to introduce these properties derived from advanced experimental techniques such as Diffusion Tensor MRI [22]-[23] or Magnetic Resonance Elastography (MRE) [24-[25] into numerical model leading to accurate simulation results.

In this present study, the simulations of facial mimics were performed with only one activated muscle (zygomaticus major). It is well-known that more muscles contribute to the facial motions. Other facial muscles will be investigated to have a more complete model leading to the simulation of muscle coordination mechanism of facial mimics.

To conclude, a facial mimics simulation was performed using MRI data and Finite Element method. Such study will be of interest for defining objective criterias to evaluate the facial disfigurement patients and to perform the functional rehabilitation.

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