Patient-specific, Fast Soft-Tissue Simulation for Cranio-Maxillofacial Surgery

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Introduction

We propose a computationally efficient and bio-mechanically relevant soft-tissue simulation method based on predicted facial muscles using a template model. Our aim is to realize delicate soft-tissue variation around lips and nose area which are the most error-sensitive regions for surgeons.

Materials and methods

Conventional Computed Tomography (CT) was used as the only input for image segmentation. Extra-cranial soft-tissue was manually segmented with commercial software (Amira, Mercury Computer Systems), followed by tetrahedral mesh generation using same software. Patient-specific facial muscles were constructed by morphing the muscles from a facial template model[1], since it is almost impossible to identify individual muscles in clinical CT. The morphing procedure was driven by a landmark-based thin-plate-spline (TPS) algorithm. In order to obtain the direction of muscle, oriented-bounding box (OBB) extraction was performed as shown in Fig.1.

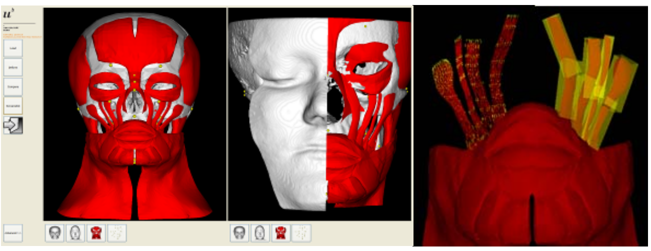


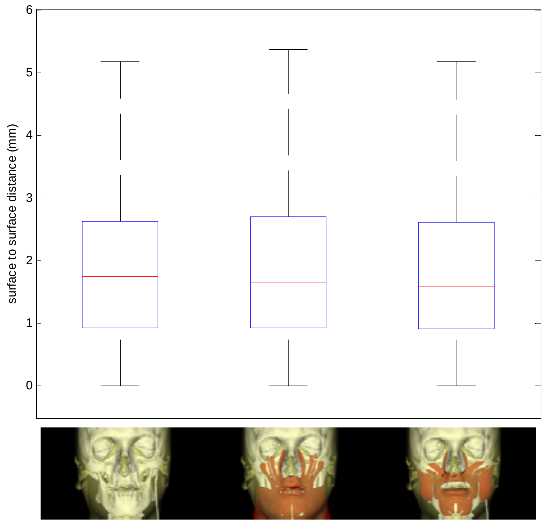
Fig. 1: Generation of patient-specific facial muscles (left), Extraction of muscle direction (right)

Finally, corresponding material properties were assigned by considering the proportion and direction of the muscle in each tetrahedron. Soft-tissue simulations were performed using mass-tensor model (MTM) with consideration of transversely isotropy of muscles.[2]

Results and discussion

The accuracy and computational efficiency of MTM was compared with that of commercial FEM software (Abaqus/CAE 6.7, Dassault Systems) using homogeneous material model. Surface to surface distance errors between FEM and MTM were only 0.023mm±0.0061mm. The overall computation of MTM was almost 18 times faster than FEM. (MTM: 3.8 sec, FEM: 67 sec), such difference can be considered even higher since the calculation of tensor matrix for MTM can be pre-processed.

Post-operative CT scan of the patient (Le Fort III osteotomy) was used to compare simulation results in different tissue models: homogeneous, transversely isotropic. Additional muscle template, originated from high resolution MRI scan, was introduced to see the effects of using a more refined template model on the simulation result.(Fig.2c)[3]



(a) (b) (c)

Fig. 2: Comparison of errors between simulations and post-operative result: homogeneous(a), transversely isotropic – template I(b), transversely isotropic – template II(c)

As shown in Fig.2, the mean error was decreased by incorporating transversely isotropy of muscles. Statistical analysis using Wilcoxon rank sum test ($p<0.05$) showed that there was statistically significant difference between homogeneous and both transversely isotropic simulations. However, no statistically significant difference was detected between two different muscle templates. These results allow us to conclude on the added value of facial muscle modeling for soft-tissue simulation in cranio-maxillofacial surgery.

References

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