A 3D FINITE ELEMENT MODEL OF THE HUMAN FACE COUPLED WITH A SIMULATOR FOR PLASTIC AND MAXILLO-FACIAL SURGERY

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A surgical simulator for plastic and maxillo-facial surgery, that gathers the dental analysis (orthodontia) and the maxillo-facial analysis (cephalometry) into a single computer assisted procedure, has been recently developed [1]. This simulator proposes a semi-automatic diagnosis for facial bone structure repositioning. This paper presents the next step of this work, i.e. predicting the consequences of the simulated bone structures displacements onto the patient face appearance. In that purpose, a 3D biomechanical model of the human face has been developed [2].

Biomechanical face model

Facial skin has a layered structure composed of epidermis, dermis and hypodermis. Many facial muscles, involved in speech production and face expression, are inserted between those skin layers and the underlying bones (figure 1).

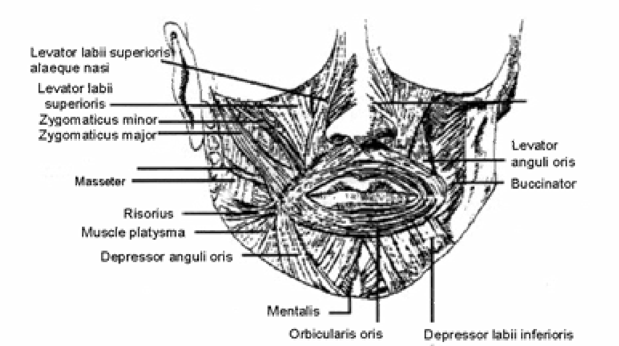

Figure 1: face muscles (from Bouchet & Cuillleret [3])

Soft tissues behaviour is visco-elastic, described using linear elasticity equations discretized in the framework of the Finite Element (FE) Method. A multi-layers volumetric mesh (figure 2) is used to model the "passives" tissues: fat and dermis layers. Biomechanical properties are chosen to replicate observations made on human skin [4]: quasi-incompressibility, isotropy, and elasticity set with a Young modulus equal to 15 kPa. Main face muscles are then defined by inserting separate FE structures into this mesh, with different properties [5]: elasticity depends on muscle activation, raising linearly from 6 kPa at rest to 110 kPa when activated, and muscle structures are orthotropic, to take into account muscular fibers directions. Dynamic simulations of face deformations under muscles actions can thus be simulated (figure 3).

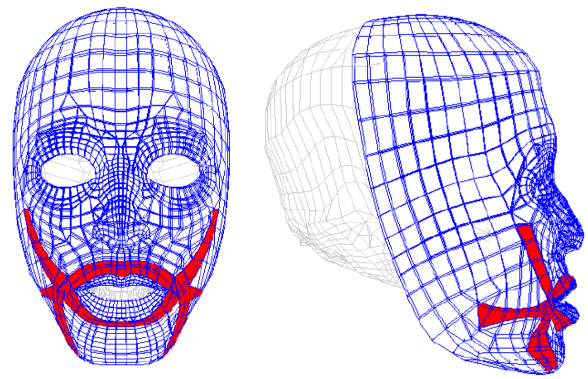

Figure 2: 3D Finite Element mesh, with main muscle structures.

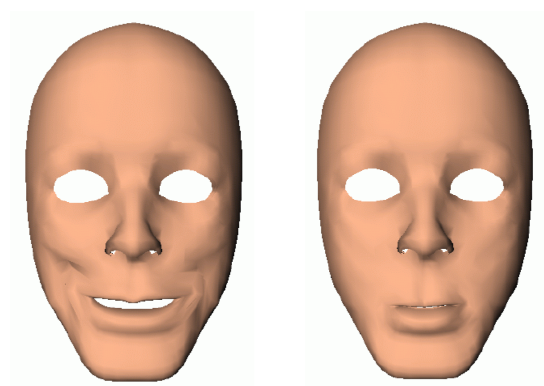

Figure 3: action of Zygomaticus major and Orbicularis oris.

Coupling the model with bone structures: first qualitative evaluation

As a first validation of our methodology, the coupling of the face model with the simulator for bone repositioning is evaluated. For this, the first step is to adapt the FE face geometry to the geometry of the skull that has been used into the first version of the bone repositioning simulator (figure 4). This is done using the Mesh-Matching algorithm [6]: in a first step, the external surface of the standard skull used to define our face model (figure 3, right) is fitted to the external surface of the simulator skull (figure 4, left). The result is a local and elastic transformation **T**. This transformation **T** is then applied to all the nodes of the FE face model, generating a new volumetric FE mesh, with an internal surface that is matched to the external surface of the simulator skull (figure 5, up).

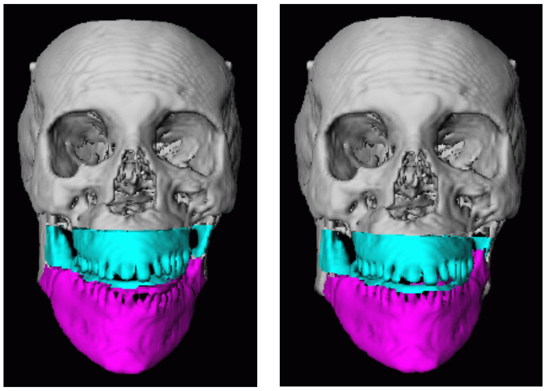

Figure 4: dry skull, before and after simulated surgery [1].

Then, nodes of the internal FE mesh surface that are closed to the mandibular region of the simulator skull are manually labeled as “mandible nodes”, while nodes closed to the maxillary are labeled as ”maxillary nodes”.
This labeling is then used to simulate the repositioning diagnosis that was originally proposed by the simulator (see [1] for details): the rigid transformation matrix (rotation and translation) provided for the mandible is applied to the “mandible nodes”, while the transformation associated to the maxillary is applied to the ”maxillary nodes”. All the other nodes of the internal surface of the FE mesh are constrained to have no displacement, while the other nodes of the FE structure (modeling the different thickness and muscles) are free to move. Figure 5, down, plots the results of the simulation.

Discussion

Those first results qualitatively validate the concept of coupling the face model with a patient skull for which a repositioning diagnosis (integrating cephalometric and orthodontic constraints) has been provided by the simulator. Face geometry matching as well as maxillary and mandibular imposed displacements can be simulated with the FE structure.
The next step will thus deal with quantitative validation on patient data, i.e. comparisons with simulated predictions and measured consequences of the surgery.

References

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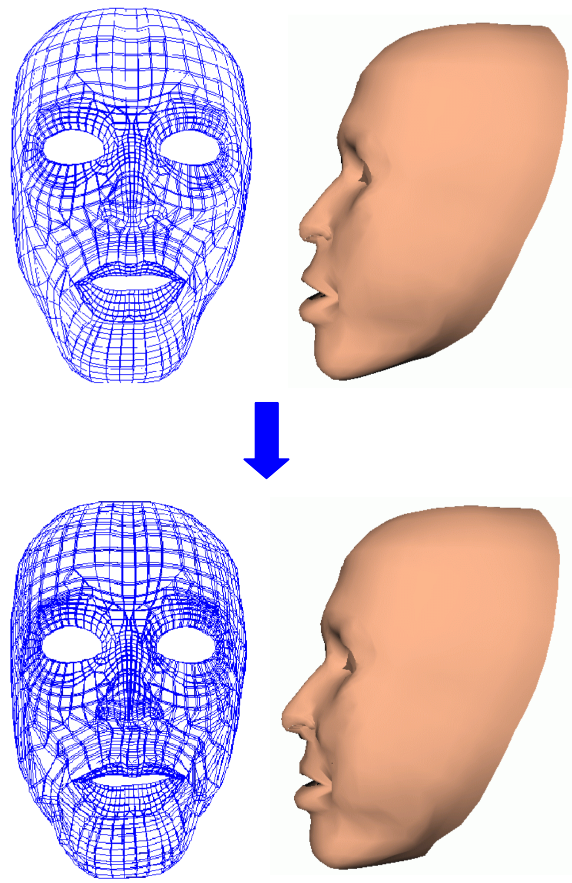

Figure 5
Up: standard mesh deformed to fit dry skull surface;
Down: mesh after applying bone replacement diagnosis.