35th Annual International Conference of the IEEE EMBS
Osaka, Japan, 3 - 7 July, 2013

The effect of bone displacement operations on facial soft tissues

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Abstract— **A novel biomechanical model for face soft tissue (skin, mucosa, and muscles) is introduced to investigate the effect of mandible and chin bone displacement on the overall appearance of the patient's face. Nonlinear FE analysis is applied to the model and the results obtained are used to help surgeons to decide the amount of displacement required.**

I. INTRODUCTION

Oral and Maxillofacial surgery is performed to correct a wide spectrum of diseases, injuries and defects in the head, neck, face, jaws and the hard and soft tissues of the oral and Maxillofacial regions [1].

The Maxillofacial surgeries start by predicting the final shape of the face depending on the CT and cephalometric X-ray images. More accurate techniques are needed for the pre analysis methods to perform well in determining the final shape predicted. The surgeons need this technique to perform well determined pre analysis methods to avoid repeating the operation to fix errors in operation.

Many research models were built since 1993.The progress starts by studying normal facial soft tissue, without taking the deformation into account. The models gradually enhanced taking in the account the deformation [4- 16], but still in need to be more realistic, and narrow the gab between the real cases and the model one [2-16].

. In this paper a new technique and methodology be used to analysis the effect of bone deformation on facial soft tissue integrating expression muscles for more accurate results using nonlinear Finite element model and material properties depend on Biomechanical properties of tissues and muscles to be more realistic.

II. MATERIAL AND METHOD

CT scan is used to apply our proposed technique. ActiViz.NET version 5.8.0, RAPIDFORM version 2, CATITA version 2, and ANSYS 2008 were used in the visualization, analysis and prediction process with core 2 duo, 4 GB RAM PC.

Using ActiViz.NET, the 3D surface of the face be created using isosurface marching cube extraction algorithm (Isosurface is a surface that represents points of a constant value e.g. bone or soft tissue density)[17], and remeshed primarily, and then the reconstructed isosurface (bone and soft tissue) be saved in STL format for further analysis[18].

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The facial expression muscles play an important rule in the face's outer shape. The model integrates facial soft tissues with the expression muscles to study the effect of bone displacement on the facial soft tissues and the overall face outer profile; figure 1 shows the insertion and location of facial expression muscles

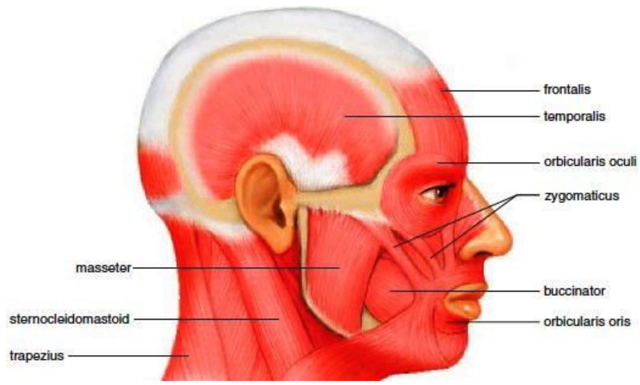

Figure 1. Facial expression muscles

A. Geometry Import & Cleanup

The STL file generated from VTk is not proper for further analysis because it contains low quality mesh, full of gaps as shown in figure 2. To reduce modeling and computational efforts, only portion of face is considered which will have the effect of jaw and chin bone displacement plus containing the expression muscles too as shown if figure 3.

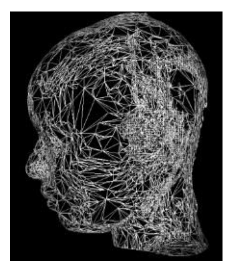

Figure 2. Output Mesh from VTK

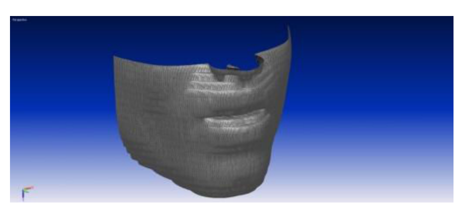

Figure 3. The model represented by STL before improvement

With the help of Rapidform the following steps were performed to improve the quality of mesh resulting from VTK:

- The STL contains a discontinued region (at the chin area), huge gap like this cause model failure, so this gap should be filled.

- After that a smoothing filter is applied on the surface to decrease computational time in analysis of this surface
- Now the skin thickness is added to the surface and remeshing the model and applying automatic mesh fixing.
- After that the surface is imported to CATIA for cleaning spikes at the edges and dividing it to soft tissue and muscle parts, under surgeons guide. Figure 4 shows snapshots of the program.

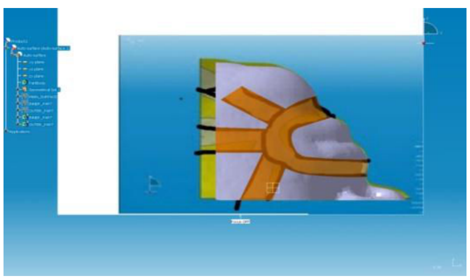

Figure 4. The final mesh after cleaning and subdivided

B. *Geometry Subdivision*

The imported mesh is divided into different regions representing the muscles and soft tissues to apply different material properties according to the region type. To apply boundary conditions, muscle, and soft tissue connection regions are specified Figure 5 shows divided and grouped areas.

Figure 5. Example of the integration of facial soft tissue and expressions muscles

C. *Element Selection and Discritization of Areas*

The mesh resulted from previous steps still not well organized and still improper for further analysis as it contains element with different shapes and sizes and due to the complexity of geometry and topology, 2D finite element modeling is considered. The face is meshed with shell elements and skin thickness is defined as a section property. Nonlinear layered shell element [SHELL 181] is selected for discritization.

SHELL181 is suitable for analyzing thin to moderately-thick shell structures. It is a 4-node element with six degrees of freedom at each node: translations in the x, y, and z directions, and rotations about the x, y, and z-axes. SHELL181 is well-suited for linear, large rotation, and/or large strain nonlinear applications [19, 20].

Another benefit of using shell element with thickness is the large number of elements in our model, and using 3D element will raise the computing time

Element size of approximately 0.75 mm used for the entire face except lips, element size of 0.6 mm used for the meshing lip region. Such fine element size used in order to capture the geometry of the face.

D. *Material Property Definitions*

The skin is considered a composite of collagen fibers three-dimensionally woven in the protein polysaccharide matrix. In order to restrict the modeling complexity and computation time, a linear elastic behavior is considered for facial tissues.

Under linear elastic assumptions, mechanical properties are determined by two parameters, the Young's modulus E and Poisson's ratio ν. The Young's modulus corresponds to stiffness of material i.e. the way it responds to external force. For the linear elasticity assumption E is approximated by the slope of the measured stress-strain curve. The Poisson's ratio measures the way a deformation in given direction can induce deformation in orthogonal directions. This elastic parameter is indirectly related to compressibility of the structure; a value close to 0.5 describes quasi-incompressibility.

Two sets of finite element structures are defined by two different sets of mechanical behaviors. The first set defines behavior of most of the elements associated with inactive tissues [skin, mucosa and fat]. According to Fung (1993) measurements, a Young's modulus value of 15 kPa is used for these tissues (E_{xx}). Skin tissues mainly are composed of water and considered as quasi-incompressible. The Poisson's ratio υ is therefore set to 0.49. Muscular fibers located along the course of facial muscles, are characterized by a second set of properties. The muscular fiber behavior and measurement reported by Duck (1990) are used for the mechanical characteristics of these "active" elements. Each element corresponding to muscular region is modeled with a transverse isotropic stress/strain relationship. This assumption requires two parameters for stiffness: a Young's modulus E_{xx} in the main fibers direction, and another

Young's modulus E_{yy} in orthogonal directions. Following Duck (1990) measurements, a stiffness value of 6.2 kPa is used for Young's modulus for E_{yy}, while E_{xx} is set to 110 kPa. The engineering material properties used for analysis are given in table 1 and shows the material properties attributes for tissue and muscular regions for a definition of the face FE model.

TABLE I. YOUNG'S MODULUS, AND POISSON RATION FOR SOFT TISSUES' REGION

Exx	15 kPa
v	0.49

TABLE II. YOUNG'S MODULUS, AND POISSON RATION FOR MUSCULAR REGION'S PROPERTY

Exx	110 kPa
Eyy	6.2 kPa
v	0.49

E. Element/Material Co-Ordinate System Definition

In order to define the fiber directions in the FE model; element coordinate systems need to be oriented such that element principal axis will be aligned with the muscle fiber axis. Multiple coordinate systems are defined in the model according to the fiber orientation for set of muscles and element coordinate systems are updated for the set of element representing these muscles. Figure.6 shows the direction of fibers in facial muscles.

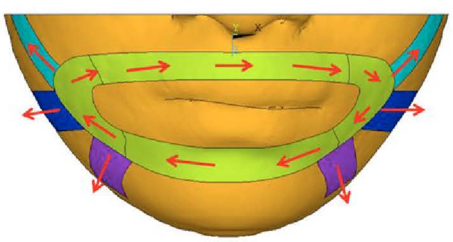

Figure 6. direction of fibers in face muscles

F. Boundary Conditions and Displacements

In order to fix the model in a space, it must be constrained at appropriate places. The section of face is constrained in all translational degrees of freedom at sectioned edges. Figure 7 shows the constrained model of the face.

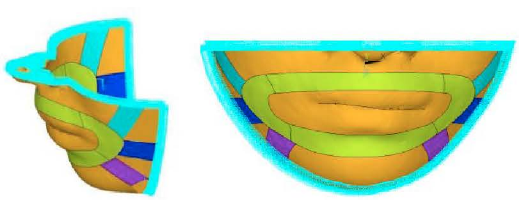

Figure 7. Constrained model

G. Nonlinear solution

The displacements applied are relatively high compared to skin thickness, as a rule nonlinear FE solution is considered. In nonlinear analysis the load is applied gradually in sub-steps. After each sub-step the updated geometry is considered for computation of system stiffness. Both jaw and chin displacements are analyzed as a nonlinear problem.

III. RESULTS

A young child CT scan is considered as a case study; surgeons decided that displacement of 5.8 mm will be applied to the jaw and followed by 3 or 4 mm displacement on the chin.

The first attempt was by taking into consideration the whole lower lips in the movement of mandible

The output result of this attempt was as in figure 8. This bad result was due to the following improper implementations: The sharp displacement which is not the case in the actual operation and taking the whole lower lip in consideration.

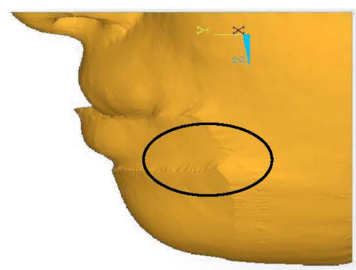

Figure 8. Output from the first attempt

To solve those problems, the displacement applied should become smoother and only the part of lower soft tissues attached to bone be considered and leave the part not attached to it free as in figure 9.

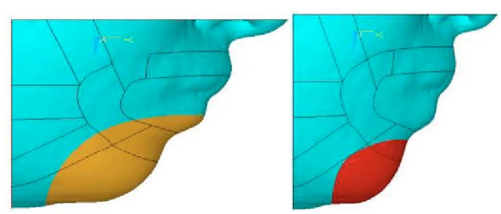

Figure 9. The smoothing displacement area(right displacement area of lower mandible area, and left for chin part)

The output resulted from these enhancements can be found in figure 10.

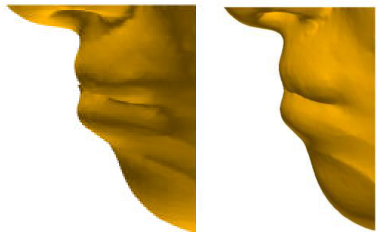

Figure 10. The resulted output from mandible displacement by 5.7 mm followed by 3mm(right),and 4mm chin movement(left)

From the overall results and by comparing it with real post operation 3D cone beam scan it can be concluded that the obtained results show fair prediction of face skin configuration after application of jaw and chin displacements. Some localized finite element modeling effect is observed in the results which show up sharp curvatures near edges of skin displacement application region; these sharp curvatures can be attributed to modeling with shell elements. But these sharp curvatures have no significant effect on overall final face shape configuration, and hence can be used to for prediction, Iteration results are provided to give the surgeons, the ability to choose between different displacement profiles

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