COMPLEX HUMAN TISSUES FEM MODELS PREPARED BY BOOLEAN OPERATIONS

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INTRODUCTION

Numbers of biomechanical applications are making computational FEM modeling of stress and strain (etc.) of selected human tissues. For these applications it is necessary to have FEM models of the tissues. Because of the tissues geometric complexity, it is often very hard or impossible to prepare the FEM models manually in FEM system. Therefore we have developed computer system for fully automatic FEM models creation from CT/MR data [Kršek 2001].

It is necessary to create very complex models as a group of tissues and another parts in interactions many times. For example bone and screw, bone and replacement, group of bones, bone with holes etc. Preparing FEM models by Boolean operations (union, subtraction and intersection) between geometry of the tissues and of another parts is one of the possible solutions of the problem.

The article is dealing with the method of creating complex FEM models by Boolean operations between fully automatically created geometry of the tissues (by our described method) and "classically" created geometry of another parts (by CAD/CAM/FEM systems).

METHODS

The our method of fully automatic creating of tissues FEM model from segmented CT/MR data [Kršek 2001] consist of several steps:

- Vectorization of selected tissues voxel models (segmented from CT/MR data) by "Marching cube" method [Lorensen 87]. On the output is oriented closed boundary triangular polygonal mesh.
- The boundary triangular mesh smoothing by modified Laplace operator with saving volume [Balendar 99]. On the output is the triangular mesh with smoothed sharp, edgy and layered character of Marching cubes mesh.
- The boundary mesh triangles number decimation by "Surface simplification method using quadric error metrics" [Garland 97]. On the output is the triangular mesh with maximal saving of boundary geometry shape and ~95% reduction of mesh triangle number.
- Quality optimization of the boundary triangular mesh [Kršek 2002]. On the output is the boundary triangular mesh with improved quality of shape of their triangles.
- Creating tetrahedral mesh as "Delaunay triangulation" based on the triangular mesh [George 98]. On the output is the tetrahedral mesh which fully fill volume of the boundary triangular mesh and respect their boundary.
- Quality optimization of the tetrahedral mesh [Freitag 99][Rivara 96]. On the output is the final tetrahedral mesh (final FEM model) with better quality of tetrahedral shape. For accuracy of following computational FEM modeling it is necessary.

In FEM systems it is normally possible to make Boolean operations, but only with basic vector geometry [Kršek 2000]. The basic geometry is consisting of key points, spline curves, and spline surfaces, which are closed to volumes. Final FEM model (tetrahedral mesh) is created after Boolean operations by functions of the FEM system.

In our method we have not created the basic geometry. Therefore, we have made Boolean operations with the triangular boundary meshes. Support for Boolean operation in our method consist of following steps:

- Obtaining the boundary triangular mesh of combined parts. For tissues are the meshes created automatically from CT/MR data by previously described algorithms (vectorization, smoothing, decimation and quality optimization). Boundary meshes of another parts with more simply geometry (screw, replacement, hole, cuts etc.) are made in CAD/CAM/FEM system.
- Boolean operation with the boundary meshes. Just before the operation is necessary move parts to right relative position. For the operation we have used classical Computer graphics algorithms with polygonal models [Žara 98]. On the output are modified boundary triangular meshes of the parts.
- Quality optimization of resultant boundary meshes. Boolean operations made many bad shape triangles in the meshes. Therefore it is necessary optimize the meshes by previously described algorithms.
- Creating tetrahedral mesh as "Delaunay triangulation" based on the meshes by previously described algorithms, with special respect to boundaries shape and interactions between tissues and parts.
- Quality optimization of the tetrahedral meshes by previously described algorithms. On the output are the final tetrahedral meshes (final FEM models) of all tissues and all parts with conformal contact.

RESULTS AND DISCUSSION

By described method it is possible to combine FEM models automatically created from CT/MR data with geometry created in CAD/CAM/FEM system [Kršek 2000]. Normally it is not possible or very hard, because we have not the basic geometry for out tissues FEM models.

On figures 1-6 are examples of complex FEM models created by described method. Initial tissues FEM models were made automatically from CT data by our programs. Geometry of additional parts was made in CAD system. Boolean operations were made at the CAD system to. Resultant geometry of modified tissues and parts was imported to our meshing system for creating final FEM models of them.

SUMMARY

We have not fully implemented algorithms for Boolean operations with triangular boundary meshes, at the time. Therefore, we have used another CAD system for the operations. Next we have imported resultant boundary mesh in to our meshing system for optimizing boundary triangular quality and creating tetrahedral FEM meshes of modified geometry. The finished FEM models are imported in to a FEM system for computational modeling.

To the future we want: finish full implementation of all needed Boolean operation; integrate Boolean operation it to our meshing system include relative positioning of tissues and parts; expanding number of import/export format (STL, IGES, DXF,) of tissues and parts geometry, testing behaviors and practical usability of described method with special focus to quality of created FEM models.

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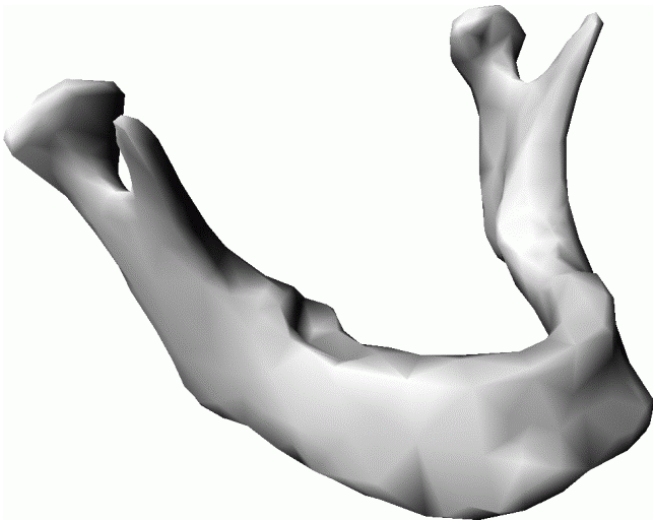

Figure 1: Initial FEM model of a human jaw

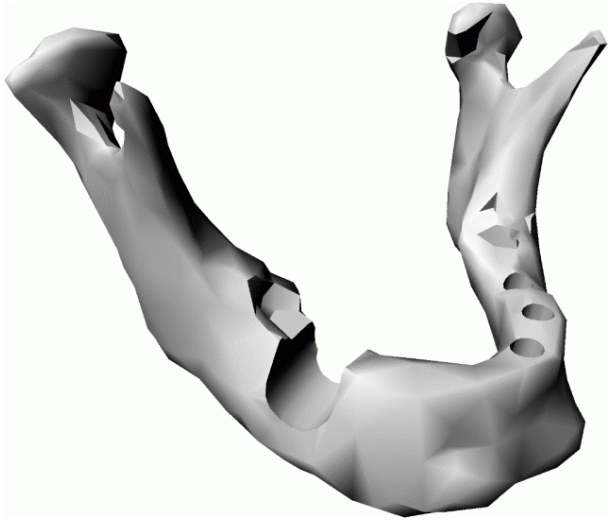

Figure 2: Modified FEM model of the jaw, a defect (on left) and three holes for screws (on right)

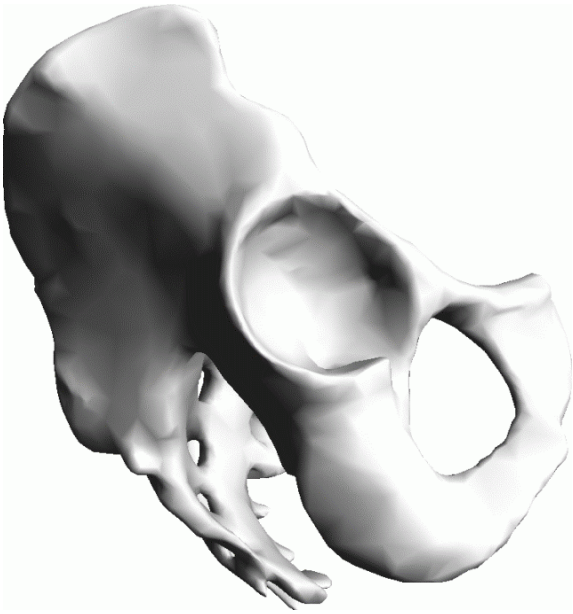

Figure 3: Initial FEM model of a human pelvis

Figure 4: Modified FEM model of the pelvis, a defect (on left) and sphere hole for a acetabulum (in center)

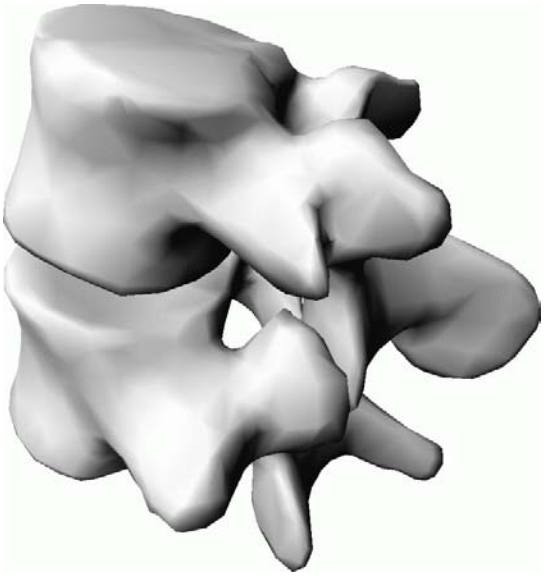

Figure 5: Initial FEM model of two human vertebras

Figure 4: Modified FEM model of the vertebras, struts holes (on up), struts sticks (down), vertebra defect