AUTOMATIC CREATING OF TETRAHEDRAL FEM MODELS OF HUMAN TISSUES FROM SEGMENTED CT/MR DATA

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Abstract: **Because of FEM computational modelling of human tissues, in number of biomechanical applications, we have needed 3D FEM models of the tissues. Manual creating of the models is often very hard or impossible, because of tissues geometry complexity. Therefore we have developed computer system for fully automatic tetrahedral FEM models creation. Input information about tissues geometry and structure we have from segmented CT/MR data.**
Keywords: **meshing, biomechanics, tetrahedron, CT, MR**

Introduction

Numbers of biomechanical applications are making computational modeling of stress and strain (etc.) of human tissues by Finite elements method (FEM). For these applications it is necessary to have FEM models of the tissues. Computer tomography (CT) and Magnetic resonance (MR) are good sources of information's about tissues geometry. So, the task is to create tissues FEM models from CT/MR data. Because of tissues geometric complexity, it is often very hard or impossible to prepare the FEM models manually. Therefore we have developed computer system for fully automatic FEM models creation from segmented CT/MR data.

Materials and Methods

Inputs of the described method are segmented CT/MR volume data. The result is a tetrahedral mesh of selected segmented tissues. It is possible to create complex conformal tetrahedral meshes of one tissue or group of tissues in contact with respect to their boundaries. Final tetrahedral mesh is imported to some FEM system (ANSYS, etc.) at last. The method consist of several steps:

- Vectorization of selected tissues voxel models by "Marching cube" method (Figure 1a) [1]. The result is a triangular mesh representing tissues boundaries.
- Triangular mesh smoothing by Laplacian operator (Figure 1b, 2a) [2].
- The mesh triangles number reducing by "Decimation of triangle meshes" algorithm (Figure 2b) [3][4]. The result is a triangular mesh with almost the same shape but with ~ 95% reduction.
- Triangles shape quality optimization by swapping or dividing wrong triangles of the mesh [6][7].
- Creating tetrahedral mesh as "Delaunay triangulation" based on the triangular boundary mesh [5]. The result is a constrained conformal tetrahedral mesh, which fills volume of the tissues.
- Tetrahedra shape quality optimization by swapping or dividing wrong tetrahedrons of the mesh [6][7].

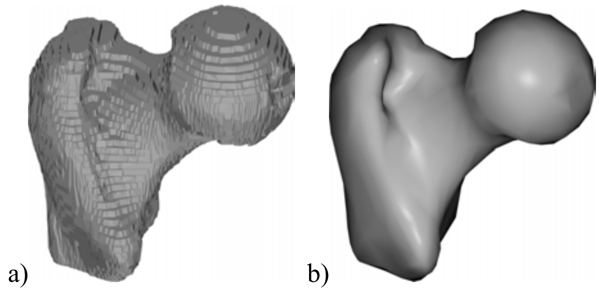

Figure 1: Femur model after marching cubes a), after smoothing b).

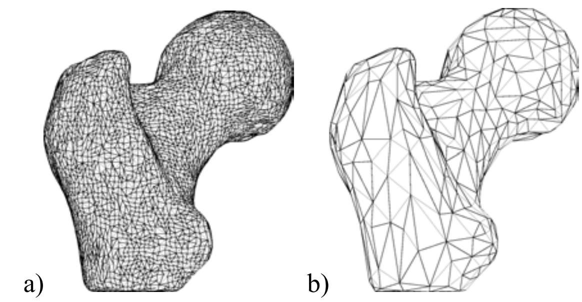

Figure 2: Smoothed femur model a), after reducing b).

Results

Our computer system [8] is working with full functionality at the time. All process is fully automatic, relatively fast and independent on complexity of tissues geometry. Next are some examples of our FEM models (Table 1, Figure 3 - 5), which has been created on PC with Pentium II 450MHz, 512MB RAM, WinNT 4.0.

Table 1: Parameters of example FEM models

FEM model	Nodes	Tetra.	Time [s]
Skull (Figure 3)	10 911	38 983	1 294
Jaw (Figure 3)	1 926	6 347	142
Pelvis (Figure 4)	6 434	23 410	905
Femur (Figure 4)	932	3 627	153
Vertebras (Figure 5)	4 842	16 675	182

Discussion

Main advantages of the described method are: independence on tissues geometry; fully automatic process of creating FEM models; speed.

Main disadvantages are: possibility creates only tetrahedral meshes; in FEM system exist only tetrahedral mesh without “basic geometry” (key-points, curves, surfaces and volumes) [9].

For many biomechanical applications it is enough to use automatically created tetrahedral meshes. But in special cases it is possible to generate a cross section curves, import them to FEM system and create FEM model by classical method from “basic geometry” [9].

Conclusions

Future improvements of our system are: better quality optimization of triangular and tetrahedral meshes; Boolean operation with tetrahedral meshes.

Shown FEM models were used for real biomechanical FEM simulations. CT/MR data was obtained from Radiology clinic, St. Anne's University Hospital Brno.

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REFERENCES

[1] Lorensen W., Cline H.: Marching cubes, A high resolution 3D surface construction algorithm. In: Proceedings, Siggraph 87, USA, 1987, s. 163-169

[2] Balendran B.: A Direct Smoothing Method For Surface Meshes. In: Proceedings, 8th International Meshing Roundtable, South Lake Tahoe, USA, 1999, s. 189-193

[3] Schroeder W. J., Zarge J. A., Lorensen W. E.: Decimation of triangle meshes. In: Proceedings, Siggraph 92, USA, 1992, s. 65-70

[4] Garland M., Heckbert, P.: Surface simplification using quadric error metrics. In: Proceedings, Siggraph 97, USA, 1997, s. 209-216

[5] George P. L., Borouchaki H.: Delaunay triangulation and meshing. 1. vyd. Paris, Hermes 1998, 413 s., ISBN 2-86601-692-0

[6] Rivara M. C.: New Mathematical Tools and Techniques for the Refinementand or Improvement of Unstructured Triangulations. In: Proceedings, 5th International Meshing Roundtable, Sandia National Lab, USA, 1996, s. 77-86

[7] Freitag L. A., Gooch C. O.: A Comparison of Tetrahedral Mesh Improvement Techniques. In: Proceedings, 5th International Meshing Roundtable, Sandia National Lab, USA, 1996, s. 87-106

[8] Kršek P.: Direct FEM models creation from CT/MR data for application in biomechanics (in czech). Science papers VUT Brno, Edition PhD Thesis, vol. 59, Brno, Vutium 2001, 30 s., ISBN 80-214-1796-X.

[9] Kršek P.: Possibilities of creation of FEM models from CT/MR data. In: Proceedings, Engineering mechanics 2000, Prag, AM AVCR, 2000, s. 27-32, ISBN 80-86246-03-5

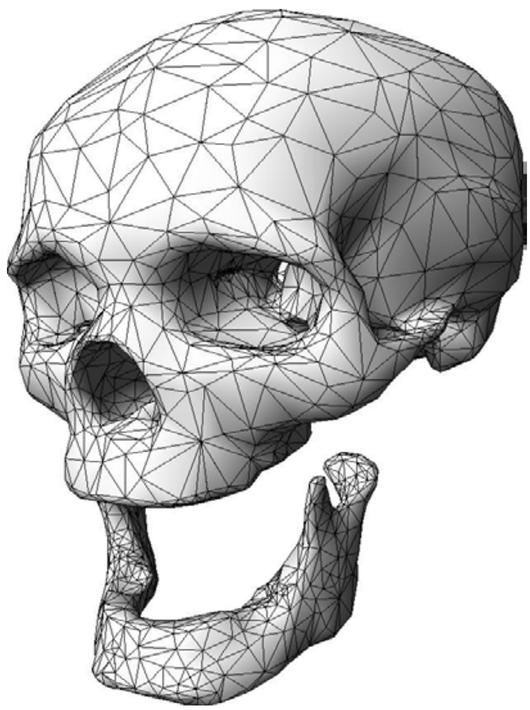

Figure 3: FEM model of human skull with jaw.

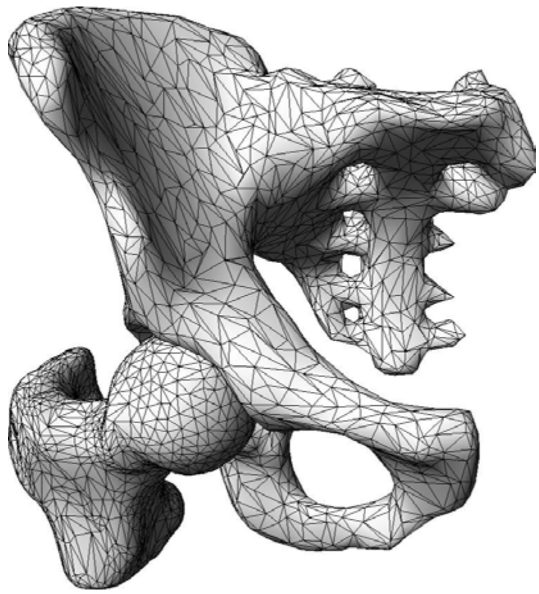

Figure 4: FEM model of human pelvis half with femur.

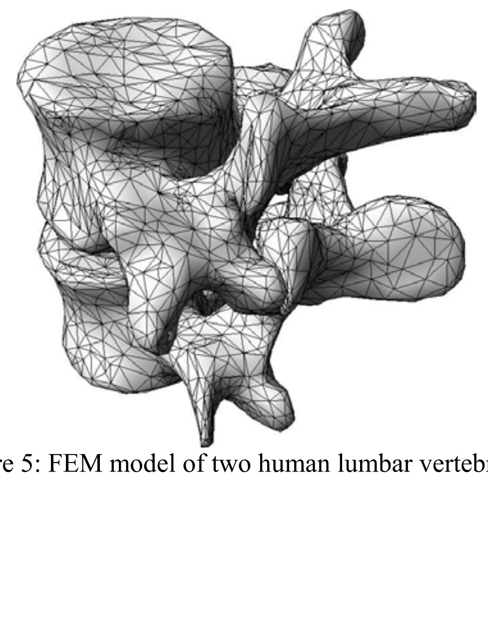

Figure 5: FEM model of two human lumbar vertebras