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OPTIMIZED FE MESH GENERATION BASED ON MEDICAL IMAGING AND ON A USER-DEFINED SPATIAL REFINEMENT GRADIENT. APPLICATION TO A MOTION SEGMENT.

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1 INTRODUCTION

In general, the starting point for the 3D geometrical modelling by finite elements of an anatomical structure is the generation of a 3D voxel-based geometrical model, obtained after denoising, smoothing and segmentation of a set of 2D medical images. The accuracy of the FE computation increases if the geometry of model resembles, for instance, the natural smoothness of real anatomical structure. Usually, the lack of detailed data in conventional imaging techniques causes further problems in the IVD finite element mesh generation and analysis. Difficulties arise mainly due to the complexity and the dimension of the IVD constituent structures and the lower resolution of medical imaging. After the 3D voxelized model has been defined, a specific isotropic tetrahedral FE meshing procedure is applied and, generally, a too dense and highly refined FE mesh is obtained. Therefore, it is necessary to decrease its size by diminishing the total number of nodes and elements while maintaining both geometrical accuracy and a physically compatible FE mesh refinement. Generally, after this procedure, the smaller elements are located at the internal and external boundaries, while larger elements are located inside the FE mesh. However, this is not always acceptable. There may be situations where this accuracy may be required simultaneously in structures outside and inside the FE mesh. In a motion segment, the FE mesh should be more refined at the IVD and coarser at the vertebrae (nearly incompressible medium). On the other hand, since the annulus fibrosus (AF) is a stiff ring-shaped structure made up of concentric lamellae [1], an optimized FE mesh should be more refined at the annulus fibrosus than at the nucleus pulposus (NP) (Fig. 1).

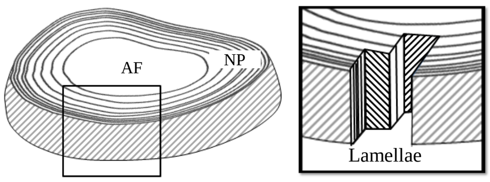


Fig. 1 Illustration of the intervertebral disc and the lamellar structure in the annulus fibrosus.

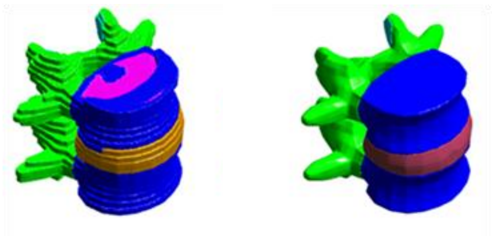
The aims of this study are:
- to study the impact of medical imaging resolution in the FE mesh accuracy;
- to develop a refinement gradient, where in this case the elements should be smaller in the outer annulus (where lamellae are denser and combined) than the ones in the inner annulus (less dense lamellae).

2 METHODOLOGY

In order to study the impact of medical imaging resolution, a procedure for the generation of a so-called "virtual 2D medical images" is designed and implemented. By defining the desired medical imaging resolution, the FE mesh is discretized and the initial 2D medical images are virtually generated and segmented, and the 3D voxel-based geometric model created. Then, a procedure based on the work of Labelle *et al.*, 2007 [2] allowing the generation of a tetrahedral FE mesh from 3D reconstructed and segmented medical imaging is applied. After FE mesh generation, it is possible to simplify this previous dense mesh in such a way that a user-defined gradient can be achieved, i.e., one needs to define, in the FE mesh, a user defined edge sizing field to drive the FE mesh simplification procedure. This so-called user-defined edge sizing field was implemented by the definition of a sizing field, in which the maximum size allowed to all edges sharing a node must be defined by the user.

3 Results and Discussion

Two different medical imaging resolutions (or voxel sizes) of 0.3x0.3x3.3 mm^3 and 0.12x0.12x0.12 mm^3 were studied. The numerical results allowed concluding that medical imaging resolution has a major role on the geometrical accuracy of 3D voxel-based geometrical reconstruction, and thus also on the reconstruction of the 3D FE meshes obtained from 2D medical imaging data (Fig. 2).



a) *b)*

Fig. 2 FE mesh obtained for the resolution of (a) 0.3x0.3x3.3 mm3 and (b) 0.12x0.12x0.12 mm3 of resolution.

In order to compare and evaluate the geometrical accuracy and the influence of different edges sizes applied in the FE meshes, axial and sagittal cross sections were realized. Fig. 3a shows the FE mesh (with a non-accurate boundary between NP and AF) obtained in a simplification test and Fig. 3b shows the FE mesh without a non-accurate boundary between NP and AF obtained with the same simplification test.

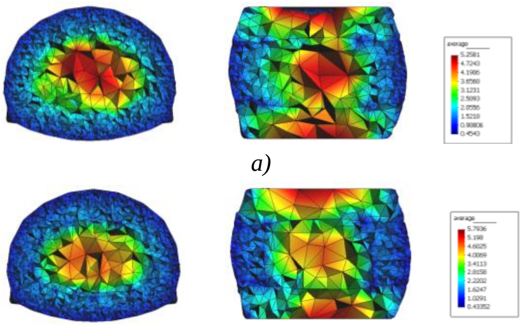


Fig. 3 Axial (left) and sagittal (right) cross sections of the simplified FE meshes obtained a) with and b) without a “non-rigorous” boundary definition between NP and AF.

Acknowledgments

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