A COHORT OF PATIENT-SPECIFIC AND VIRTUAL FINITE ELEMENT MODELS OF INTERVERTEBRAL DISCS AND MODEL VALIDATION

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Introduction

Finite element (FE) analyses have been used to study human tissues and organ biomechanics. However, automating patient-specific (PS) Intervertebral Disc (IVD) models can take time and effort to explore the poromechanical behavior of tissues under large deformations [1], and no cohorts have yet been generated to explore the particularities of morphology or whether the latter can be a factor in IVD degeneration (DD) [2]. This work aims to generate a FE mesh repository of PS models through a morphing process and extend it through a virtual cohort employing a statistical shape model (SSM). Simulations are performed to explore the effect of morphology and validate the modeling approach.

Materials and Methods

169 3D shapes of lumbar IVDs, from healthy to grade 4 degeneration states, generated during the European My Spine project (FP7-269909), were obtained from MRIs [3]. The segmentations included the annulus fibrosus (AF) and the nucleus pulposus (NP). The Bayesian Coherent Point Drift (BCPD) algorithm rigidly and non-rigidly aligned the meshes [4] to a previously validated structural mesh of the IVD to PS IVD segmentations [1]. Mesh morphing was carried out in seven stages to end with a mesh quality analysis and test the similarity between the morphed model and the segmentation through Hausdorff distance. Cartilage endplates (CEPs), not visible in the images, were created automatically, with a height between 0.7 and 1 mm. Synthetic IVDs were generated by SSM using the PS cohort. Mechanical simulations of physiological loads were performed, considering a swelling step, 8 hours of sleep, and 16 hours of daytime, applying 0.11 and 0.54 MPa of pressure on the upper CEP, respectively. The modeling approach was validated using the experimental data reported in [2]. FE-predicted displacements were obtained for a model morphed to the tested specimen, by imposing a compressive load of 500 N, which increased linearly from 0 to 10 s, then maintained for 3 h (creep).

Results

The first twelve modes of the SSM cover 90% variability, of which the first 3 represent coronal (46 to 52 mm), sagittal (34 to 40 mm), and height (7 to 17.5 mm) width, that cover healthy and DD models according to the Pfirrmann grading system [5] (Figure 1). There were no differences when comparing the mesh quality of the template model with the PS models, so BCPD maintains the proportions of the relative distances between the nodes. A 94% similarity was obtained between the AF and NP segmentations with their respective meshes. The mechanical variables, such as pore fluid velocity, show substantial variations in the transition zone (TZ) between AF and NP. Clinical imaging has shown DD onsets in the same TZ [6]. The relative error between the simulation of this validation and the experiment was 5.20% and presented a similar curve to the simulation of the previous work.

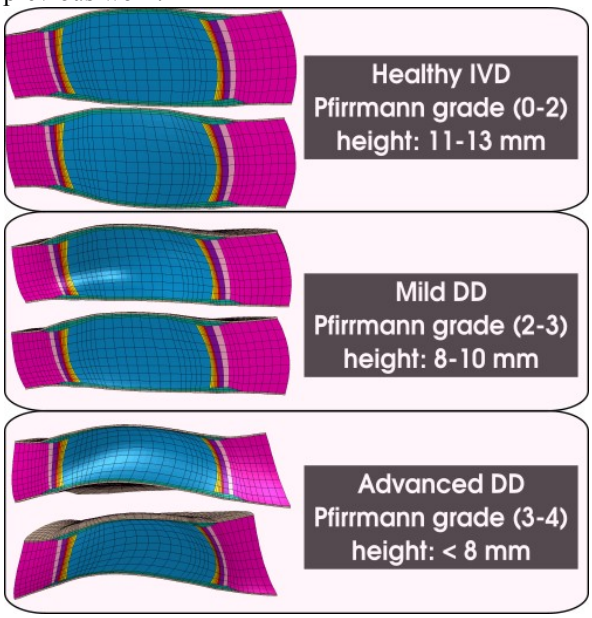

Figure 1: Models generated with different heights.

Impact

The cohort is a unique set of models to explore the effect of multiple geometric variations on the multiphysics and mechanobiology of IVD, including the full organ tissue structure [2]. The algorithm can create PS FE models from any segmented surface provided by third parties and generate thousands of representative synthetic models of healthy and DDs.

References

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