CONVERGENCE SENSITIVITY OF THE KINETIC AND MECHANICAL PREDICTIONS OF LUMBAR SPINE FINITE ELEMENT MODELS

Ugur M. Ayturk, MS
Christian M. Puttlitz, PhD
Department of Mechanical Engineering, Colorado State University, Fort Collins, CO.

Background

Mesh refinement is a crucial step in the generation of all finite element (FE) models. This is particularly relevant in modeling of spinal segments wherein voxel-based imaging data usually supply the physiologic information for geometric reconstruction. In such cases, the mesh generation frequently requires the use of certain simplification and smoothing algorithms. Consequently, the reference geometry is functionally dependent upon the mesh density and its alterations. Given this, this current study focused on how mesh refinement affects the convergence behavior and predictions of certain mechanical and kinetic parameters.

Methods

Using CT scans of a 49 year old female subject, four nonlinear FE models of the L3/L4 functional spinal unit (FSU) were created. Image segmentation, simplification and smoothing, and initial meshing with four-noded tetrahedral elements were conducted in AMIRA (ver 4.0, Mercury Computer Systems Inc, Chelmsford, MA). Transformation of the preliminary elements into eight-noded hexagonal elements with a custom-written code in Visual Basic yielded four meshes, with the number of elements ranging from 27,000 to 88,000. Utilizing ABAQUS CAE as a pre- and post-processor, linear properties of the osseous tissues and nonlinear properties of the soft tissues were adapted from the literature and implemented in all models[1-4]. Trabecular bone material properties were calculated from the Hounsfield attenutation data and quantified into 15 distinct material property sets[5]. All models were loaded with pure moments via the application of 7.5 Nm at the superior endplate of L3 in three principal directions (flexion-extension, lateral bending and axial rotation) while the inferior endplate of L4 was kinematically constrained. Range of motion (ROM), total force transmission in the facets, intradiscal pressure in the nucleus and von Mises stresses in the annulus ground substance were recorded in all simulations. Calculations were performed with ABAQUS Standard (ver 6.6, HKS, Pawtucket, RI).

Results

The change in ROM as a result of the change in mesh density was less than one degree in all directions (Figure 1). On the other hand, force transmission in the facets increased by 16 N, corresponding to a 29% difference, under extension loading. While no change was observed in facet force transmission under axial rotation, von Mises stresses varied by up to 49 %. Specifically under extension loading, a strong correlation between intradiscal nuclear pressurization and facet force transmission was noted (Figure 2).

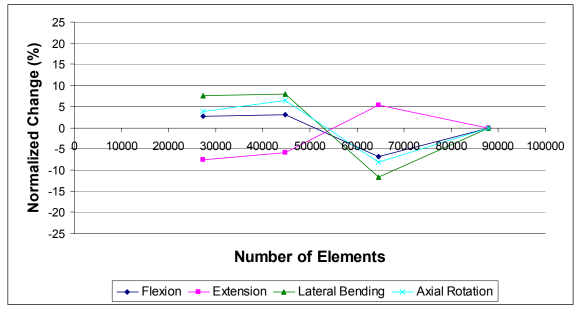

Figure 1: Change in ROM predictions as the mesh density is increased.

Discussion

The similarity of the convergence behaviors of maximum pressure in nucleus and total facet force transmission demonstrates that there exists a distinct load-sharing relationship between the nucleus and the facets under loading in extension. The variation in ROM was minimal as compared to the other parameters of interest (Figure 2). Our results suggest that the mobility of the FSU clearly does not represent the load sharing or the internal mechanics of its constituent tissues. Furthermore, FE models that use only kinematic or kinetic data as convergence and/or validation criteria should not be considered "validated" with respect to internal mechanical parameter predictions such as stresses and strains.

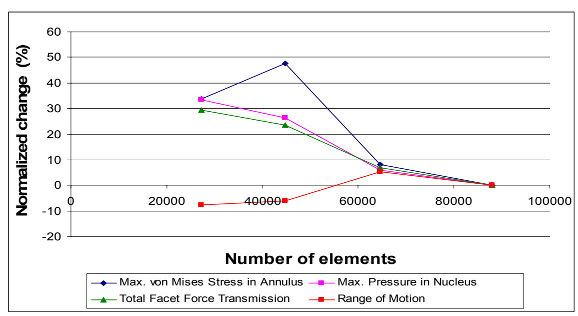

Figure 2: Normalized change in all mechanical parameters with respect to mesh density in extension.

References

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