Poster #026

Finite element modeling of the full lumbar spine with an intervertebral disc nucleus replacement device

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Introduction

- Nucleus replacement technologies are a minimally invasive treatment for degenerative disc disease.
- Nucleus replacement may better restore the natural biomechanics of the spine compared to alternative treatments.
- Finite element (FE) modeling can be used to determine the biomechanics associated with nucleus replacement devices.
- A novel nucleus replacement device was developed consisting of a conforming silicone implant with two chambers.
- FE modeling compared the biomechanics associated with the novel device, a solid silicone device, and a normal disc.
- A model of the full lumbar spine was used to investigate the effect of device placement in one level on adjacent levels.

The objective of this work was to develop a FE model of the full lumbar spine that incorporates nucleus replacement devices and determine the resulting biomechanics.

Materials and Methods

- A 3D FE Model of the T12-L5 lumbar vertebrae was constructed from CT data.
- Vertebral bodies were semi-automatically segmented from the imaging data and meshed.
- Intevertebral discs constructed by space-filling area between vertebral endplates.
- Tension only springs were added to model ligaments.

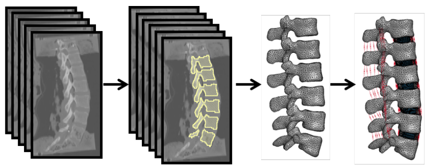

Figure 1. Image processing pathway from CT data to segmented data to mesh to adding discs and ligaments to create the full model.

- Normal disc properties and ligament properties were derived from literature references [1-4] and given in Table 1.

Table 1. Material properties for model

Structure	Property	Value(s)	
Nucleus Pulposus	Bulk Modulus (GPa) [1]	1.7	
Annulus	Young's Modulus (MPa) [2]	4.6	
	Poisson's Ratio [2]	0.45	
	Viscoelastic Coefficients [3]	Coefficient (G)	Characteristic times (τ)
		0.026	1 s
		0.022	0.1 s
		0.089	0.01 s
		0.77	0.001 s
		0.095	∞
Ligaments	Force-Displacement Curves [4]	From [4]	

Materials and Methods

- Bone properties based on quantitative CT intensity values [5].
- Novel device consists of two silicone chambers surrounded by a textile band. Outer chamber is filled with silicone and inner chamber is void.
- Additional solid silicone device created as equivalent to novel device except without inner chamber void and textile band.
- FE model of novel device and solid device replaced the L3-L4 intervertebral disc nucleus.

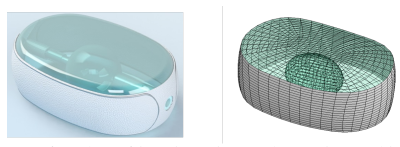

Figure 2. Left: Rendering of the nucleus replacement device, Right: FE model of device, with outer chamber shown in teal and textil3 band shown in white.

- Experimental compression and tension testing of silicone samples was used to determine the FE material model for silicone.
- Textile band material properties determined from experimental tension testing of the band.
- All simulations were performed in LS-Dyna
- Loading based on the ASTM F2423 standard [6]. Either compression or rotation applied to T12 with L5 constrained.
    - Compression: 1200 N
    - Rotation: Flexion/Extension ±37.5 degrees
      Axial Rotation ±15 degrees
      Lateral Bending ±30 degrees

Results

- Under compressive loading, the novel device resulted in slightly more axial displacement, and the solid device resulted in less axial displacement compared to baseline (normal disc).
- The displacement of adjacent levels remained unchanged with the introduction of the devices.

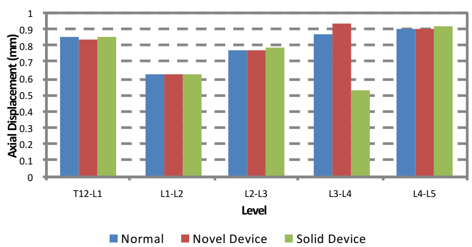

Figure 3. Comparison of the axial displacement of each level in the full lumbar spine with reference to the most posterior vertebrae in the level.

Results

- The solid device resulted in higher endplate stress than the normal disc and the novel device.

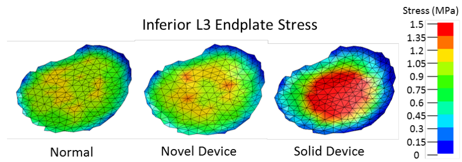

Figure 4. Comparison of the inferior L3 endplate stress between the normal disc, with the novel device, and with the solid device.

- Under rotation loading, the solid device resulted in less L3-L4 annulus stress compared with the novel device and the normal disc. The annulus stress under flexion is shown in Fig. 5
- The annulus stresses in adjacent levels remained unchanged with the introduction of the devices.

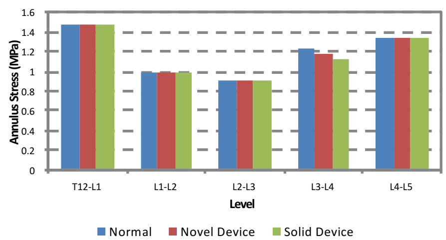

Figure 5. Comparison of the annulus stress in the disc of each level in the full lumbar spine under flexion loading.

Discussion

- We have developed a finite element model of the full lumbar spine that incorporates a novel nucleus replacement device.
- The full spine biomechanics were determined with a nucleus replacement device placed in a single level.
- Placement of the device did not have adjacent level effects on axial displacement under compression loading or annulus stress under rotation loading.
- The solid device resulted in less axial displacement, more endplate stress, and less annulus stress compared with the novel device and the normal disc.

References

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