Total Disc Replacement Positioning Affects Facet Contact Forces and Vertebral Body Strains

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Introduction: Lumbar total disc replacements (TDRs) are intended to restore the disc height, correct segmental lordosis, and preserve segmental range of motion (1). However, complications include subsidence of the metal endplates into the vertebral body (2,3) and facet arthrosis at the implanted level (4). It is not clear what contributes to these complications, but improper positioning of the TDR is among one of the suspected factors (5). The objective of the current study was to evaluate how alterations in vertebral kinematics arising from TDR implantation and positioning contribute to implant subsidence and facet joint arthrosis. We used a nonlinear 3-D finite element model of L3-L4 with a TDR implanted at two different positions along the sagittal midline to determine vertebral cancellous bone strains and facet contact forces.

Materials and Methods: A FE model of a ligamentous L3-L4 motion segment was generated from QCT data of a cadaveric spine. Bone mineral density (BMD)-dependent orthotropic material properties were assigned to the cancellous bone of the vertebral bodies (6,7) (Figure 1). The posterior elements were modeled as linear elastic, the nucleus as an incompressible fluid, and the annulus as hyperelastic orthotropic (8). Major spinal ligaments (ALL, PLL, ISL, SSL, ITL, CL, LF) were implemented in the model using tension-only nonlinear springs (9,10). The intact model was validated using disc pressures, cortical and endplate strains, and kinematic data from peer reviewed literature (11,12). An appropriately sized model of the ProDisc-L (Synthes, West Chester, PA) was placed in the intervertebral disc space at two locations along the sagittal midline a distance of 4 mm apart resulting in a "posterior" and "anterior" placement. An equal amount of the lateral annulus was preserved for both models. The implanted models were exercised in flexion (7.5 Nm), extension (7.5 Nm), right axial rotation (7.5 Nm), and right lateral bending (7.5 Nm) with a 500 N compressive follower load applied to the superior endplate of L4. Frictionless contact was defined between the facets using a penalty-based contact algorithm. The facet contact forces (FCFs), vertebral body cancellous bone von Mises (VM) strains, and ranges of motion (RoM) were determined.

Results: Facet contact forces (FCFs) increased with implantation of the TDR for flexion and axial rotation regardless of implant positioning (Figure 2). The FCF in extension increased with anterior placement and decrease with posterior placement. ROM increased with implantation of the TDR for all modes of loading. Anterior placement of the TDR allowed more ROM in flexion while posterior placement allowed for more extension. The decreased FCF in extension for the posteriorly placed TDR coincided with an increased range of motion. The opposite trend was true for flexion. The FCF in lateral bending increased with posterior placement and decreased with anterior placement. Contour plots of VM strain indicated high stresses around the posterior edge of the metallic endplate in flexion and extension for both implant positions (Figure 3). In general, strain maxima were observed around the edges of the TDR.

Discussion: Data from the current study indicate that TDR increases facet contact forces in flexion by an order of magnitude. The increased FCFs result from increased anterior translation, arising from the inferior location of the center of rotation for the ProDisc. Similarly, the FCF in extension was reduced with posterior placement of the TDR. However, anterior placement resulted in an increased FCF in extension, suggesting that the increased translation was not great enough to move the facets out of contact. Our findings suggest an increased dependence on the facets to limit range of motion after TDR. Facet arthrosis documented clinically in spinal segments with TDR may be the result of increased loading from greater joint mobility regardless of implant positioning. Anterior placement of the TDR resulted in a reduced area of high strain around the posterior edge of the device in extension. This coincided with increased FCFs, suggesting that vertebral body loading in extension is reduced when the facets participate in resisting the load. Areas of high strain were also documented along the anterior edge of the TDR in flexion, suggesting that implant subsidence and anterior migration may be the result of activities that place the spine in flexion. The lack of dependence on implant positioning and apparent correlation with increased RoM suggests that implant subsidence may result from an increase in joint mobility.

References: 1.Mayer and Korge 2002 Eur Spine J; 2. Bertagnoli et al., 2006 J Neurosurg Spine; 3. David 2007 Spine; 4. Shim et al., 3007 Spine 5. Marshman et al., 2007 Spine J; 6. Morgan et al., 2003 J Biomech; 7. Ulrich et al., 1999 Bone; 8. Eberlein et al., 2001 Comp Meth Biomech Eng; 9. Rohlmann et al., 2006 J Biomech; 10. Schmidt et al., 2006 Clin Biomech; 11. Frei et al., 2001 Spine; 12. Niosi et al., 2006 Eur Spine J; 13. Rousseau et al., 2006 Spine J

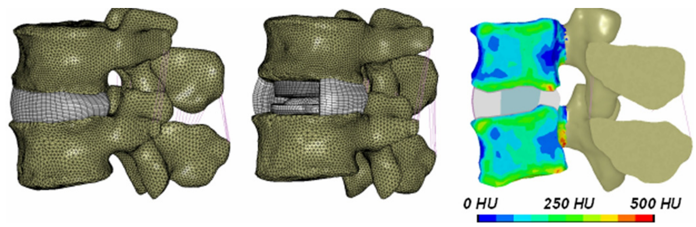

Figure 1. The intact (left) and implanted (middle) FE models with a contour mapping of the Hounsfield Units (HU, right) used to assign BMD

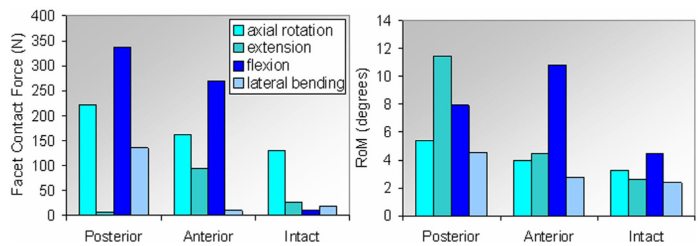

Figure 2. FCF (left) and RoM (right) for the implanted and intact models during all modes of loading

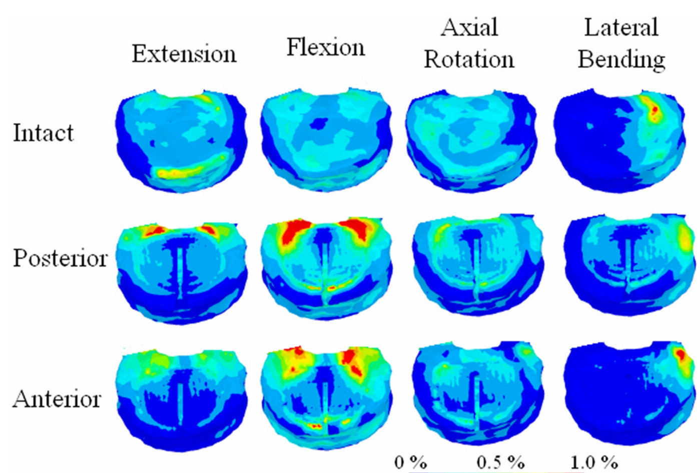

Figure 3. Effective (VM) strain contour plots of the L4 vertebral body cancellous bone at the superior endplate