INTRODUCTION: Surgical intervention for the treatment of low back pain over the last decade has often included the use of interbody fusion devices (IFDs). Implanted into the intervertebral space, these devices serve as structural support until fusion occurs. Numerous experimental investigations have evaluated the acute kinematic stability and/or monotonous strength of the implant-vertebrae constructs. A few finite element analyses (FEA) have focused upon bone-implant interactions; however none have incorporated complex material behaviors even though this interface directly affects postoperative stability and therefore success.

The objectives of this investigation were to determine the difference in predicted damage accumulation adjacent to two different IFD geometries and to determine the effect of the inclusion of viscous material behavior on the model predictions relative to results from a previous experimental and histological study [7].

METHODS: Generic cylindrical and hexahedral IFD geometries were incorporated into idealized 2-D, plane strain models generated from QCT data of the experimental specimens (Fig 1). Medial-lateral and inferior-superior symmetry were utilized for computational efficiency. The vertebral endplates and were respectively assumed to have uniform thicknesses of 0.3 and 0.5mm.

The four materials identified within each model (vertebral shell, vertebral centrum, vertebral endplate and implant) were assumed to be homogeneous and isotropic. Elastic modulus and Poisson’s ratio values from the literature were assigned to the vertebral endplates, the vertebral shell and the cylindrical implant (1000MPa, 0.2; 5000MPa, 0.3; and 110GPa, 0.3 respectively). The central cavity of the hexahedral implant was modeled as a solid cross-section with a reduced modulus (2.9GPa) to compensate for this structural modification. The elastic properties for the cancellous vertebral centrum, vertebral endplate and implant) were respectively assumed to have uniform thicknesses of 0.3 and 0.5mm.

In addition to the plasticity parameters, the 2VP material behavior (Fig 2) requires a creep law for the viscosity coefficient (Ω), the elastic moduli (E, E, and E, [E, +E]), and time constant (τ). τ was determined from the fit of a five parameter linear viscoelastic model to the experimental data and (1-E/E) chosen as 0.25 (2VP) based upon prior work in our laboratory. Using a time-hardening power law, absent the transient and non-linear viscoelastic terms, the viscosity coefficient was then determined for each model.

The bone-implant interface was modeled as a contact pair with finite sliding. The tangential behavior was implemented with an isotropic friction coefficient of 0.2 [5, 6].

RESULTS: For both devices, the predicted damage zone was localized near the bone-implant interface. In the PLH material model at both 1% and 2.5% structural strain, the typical PEEP strain distribution was on the right side of the device as a maximum at the lateral corner. (Fig 3). On the other hand, the force-displacement curves showed little difference between the two IFD geometries at either 1 or 2.5%.

Fig 3 PLH material model PEEP results at 1% structural strain

DISCUSSION: The predicted inelastic strain regions adjacent to the IFD varied between the two device geometries. The FEAs suggest that the inelastic zone adjacent to the cylindrical IFD was larger though of a lower magnitude than that of the hexahedral device. However differences due to the IFD geometry were not detectable from the structural force-displacement curves. These global effects are consistent with a previous experimental study [2]; i.e., the bone-implant construct strength was not affected by IFD geometry. However, the results of the current study show that the IFD interface designs result in very different damage zones adjacent to the devices. Given that damage accumulation is likely involved in the failure and inelastic behavior of cancellous bone, construct strength should not be the sole criteria upon which an implant is judged.

Inclusion of viscous behavior dramatically affected the predicted damage zones and structural effects and improved the comparison to the measured experimental results. Several studies have shown both pre- and post-yield cancellous bone behavior to include significant viscous effects. To our knowledge, only one other study has incorporated time-dependent material behavior [1].

A number of simplifying assumptions were made in this model. First was the use of a continuum representation. While large scale FEA permits the examination of local tissue strains, the extremely high computational cost was not judged to be justified in this initial study of nonlinear material behavior. Second was the coupling of plastic flow and damage. This choice has been used by others, and was assumed because of the lack of good data for explicitly decoupled damage-plasticity models.

In spite of model limitations, insights into a number of features were obtained through its use. The results suggest that very local damage accumulation can occur at moderate loads and these effects are not detectable by global experimental measures. Variations in these local effects with device geometry emphasize the importance of local geometry in design and application of intervertebral devices.