THE BIOMECHANICAL EFFECTS OF KYPHOPLASTY ON ADJACENT NON-TREATED VERTEBRAL BODIES: A FINITE ELEMENT ANALYSIS

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INTRODUCTION:
To date, ex-vivo experimental studies of kyphoplasty have focused on the production of clinically-relevant fracture models and the effect of variations in injection, material, or technique on the resulting biomechanical performance of the operated vertebra.[1-3] There exist few computational models in the literature designed to evaluate or predict the biomechanical behavior of a vertebral body or of vertebrae adjacent to the treated vertebra following kyphoplasty.[4-6] The goal of this study was to quantify the stress levels in the bone cement and in the bone of treated and adjacent vertebral bodies following kyphoplasty under in vivo-like loading conditions. We propose the hypothesis that the presence or absence of the bone cement bolus would not substantially alter the overall load transfer or stresses within the treated vertebral body or in the adjacent vertebral bodies. We tested this hypothesis by evaluating a finite element model consisting of two functional spinal units (T12-L2).

METHODS:
A finite element model for T12-L2 (Figure 1) was generated using meshing software (TrueGrid®, XYZ Scientific, Inc.) such that a clinically relevant bone cement region was defined within the middle vertebral body (L1) using our previously reported modeling approach.[7] The total volume taken by the bone cement and the interface elements was approximately 13.4%, in line with reported clinical practice. Analyses were run using LS-Dyna (LSTC, Livermore, CA).

Material and element properties for bone (endplate, cortical, and cancellous) and bone cement were extracted from the literature. The endplates and cortical shell were modeled with a 0.25 mm thick shells and a modulus of 1000 MPa, and 0.4 mm thick shells and a 5000 MPa modulus, respectively. The cancellous bone was characterized as osteoporotic (E=25 MPa), the modulus for the bone cement was varied from 2GPa to 4 GPa. The intervertebral discs were represented as degenerate (by stiffening both the nucleus and annulus), as this condition has the most relevance to osteoporotic vertebrae.[8] A representative in vivo loading (800N) was applied to the model (as a pressure) on the superior endplate of T12. The model was validated by comparison to experimentally-derived vertebral bone strain data.[9]

The output variables of interest included maximum and minimum principal stresses and strains in the bone cement, endplate, and cancellous and cortical bone. In addition, we examined overall and axial model deformation.

RESULTS:
In comparison to the model with no bone cement, the inclusion of bone cement (of either modulus) had a minimal effect on the stresses in the surrounding cancellous bone (11% increase in von Mises), and minimal effect on the cancellous bone of the adjacent vertebral bodies. Cancellous bone peak compressive stresses in the untreated (0.75-1.05 MPa) and kyphoplasty-treated (0.74-1.10MPa) models were both under or close to the lowest bound of the reported range of maximum ultimate strength of cancellous bone (1.4-4.6MPa).[10] A comparison of stress patterns between the treated and untreated level (L1) shows minor differences in the stress distribution in the cancellous bone immediately around the bone cement plug (Figure 1). In addition, there were only minor increases in the adjacent level (T12 and L2) cancellous bone stresses due to the presence of the bone cement in L1 (Figure 1). Minor increases in disc nucleus pressures were observed following treatment, but these were within the range considered normal (<0.7 MPa).[9] Bone cement stresses in general were always lower than 1.75 MPa, and as such were lower than reported strengths of commercial bone cements.

The stresses in the cortical shell of the level above the treated body decreased up to 3.3%, while those of the level below increased up to 3.8%. The peak compressive stresses predicted in the cortical bone, both in the untreated (11.9-17.63MPa) and kyphoplasty-treated simulations (11.51-18.30 MPa), were within a range not expected to cause damage if compared to the ultimate compressive strength of skull cortical bone. Maximum endplate von Mises stresses in the treated and adjacent vertebral bodies decreased with the inclusion of the bone cement bolus, by at least 3.7% and 4.6%, respectively. The total deformation of the model decreased with the presence of the bone cement by about 5.7%.

DISCUSSION:
Review of the clinical sequelae of patients with at least one vertebral compression fracture suggests a 5x risk of subsequent fracture.[11] some of which may be adjacent and some which may be remote to the index fracture. Authors of previous studies using finite element models of single lumbar functional spinal units have suggested that augmentation may lead to collapse of adjacent vertebrae.[4-5] These previous models have the inherent limitation of modeling only a single FSU and therefore may not have sufficient geometric separation between the effect being studied and the effect of the boundary condition affixed to the untreated level. The data in this multiple FSU study, and a recent retrospective clinical study,[12] suggest that changes in stresses and strains adjacent to a kyphoplasty-treated level are minimal, and therefore that subsequent adjacent level fractures are likely to be related to the underlying etiology and not the surgical intervention. The results presented here suggest that adjacent non-treated vertebral bodies do not undergo immediate biomechanical changes arising from kyphoplasty treatment.

Fig. 1. Sagittal views of the 2FSU model showing the von Mises Stress distribution (MPa) in the osteoporotic cancellous bone with a 4GPa bone cement plug in the middle (L1) vertebra (top series) compared to the model with no bone cement (bottom series). Disks are not shown. The mm denote distances from mid-sagittal plane.

REFERENCES:

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