Reduced Rate of Proximal Junctional Fractures Above Long-Segment Instrumented Constructs Utilizing a Tapered Dose of Bone Cement for Prophylactic Vertebroplasty – A Biomechanical Investigation

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INTRODUCTION

Proximal junctional kyphosis (PJK) and proximal junctional failure (PJF) are an increasingly recognized complication after long-segment instrumentation for the correction of kyphosis and scoliosis. Vertebral compression fractures (VCFs) at the upper instrumented vertebra (UIV) and the UIV + 1 have been described. Prophylactic vertebroplasty has been advocated to reduce the rate of VCFs but still results in the creation of a stiff "super vertebra". We hypothesize that utilizing a tapered dose of bone cement in the UIV, UIV + 1, and UIV + 2 eliminates the creation of a "super stiff" vertebra further decreasing the rate of VCFs and PJK.

METHODS

A biomechanical cadaveric study along with finite element analysis (FEA) was utilized.

Fifteen fresh-frozen ligamentous T6 - pelvis specimens were used. The spines were equally divided into three Groups of 5 specimens each: Group 1 - Bilateral pedicle screw and rod instrumentation from T10 to S1, no cement; Group 2 - Instrumentation + 4cc of cement injected into T10 (UIV) and 4cc into T9 (UIV + 1), 2cc of cement injected through each pedicle; & Group 3 - Instrumentation + 4cc total in T10 (UIV), 3cc total in T9 (UIV + 1), and 2cc total in T8 (UIV + 2). Dual-energy X-ray absorptiometry (DEXA) was obtained on all specimens. The pelvis and T6 vertebra of each specimen were fixed in bondo epoxy resin. The spines were mounted on a MTS biaxial load actuator and axial compression was applied eccentrically, 10 mm anterior to the center of the T6 vertebra, until failure occurred. Maximum load to failure was measured in Newton (N). The spines were also analyzed visually, fluroscopically, along with computed tomography (CT) scans for the presence of VCFs.

Finite element analysis (FEA) was utilized to simulate similar scenarios for the three groups as the cadaveric study using normal and osteoporotic bone models. An axial compressive load was applied perpendicular to the top of T6 vertebra, 10 mm anterior to its center just like the cadaver study. Stresses at the endplates and the posterior ligaments were analyzed.

RESULTS

Cadaveric Data

There was a significant reduction in the number of fractures (Fig. 1) observed in Group 3 vs. Groups 2 and 1 ($p=0.0019$). There was only one fracture in one specimen observed in Group 3; all five specimens suffered a fracture in Group 2; and five in Group 1. Posterior ligamentous rupture occurred in four specimens in Group 3; three in Group 2; and only one in Group 1. The mean peak load-to-failure values showed an increasing trend from Groups 1 to 3, but were not significant ($p=0.38$). Load vs. deformation plots in specimens that failed exhibited a peak load (inflection point) followed by an obvious loss of structural integrity (Figure 2). There was no difference in DEXA values among the specimens in the three Groups (p=0.71). There was no hardware failure in any Group.

<u>Finite Element Analysis (FEA) Data</u>

Load to failure in normal bone was higher in comparison to osteoporotic bone, which followed the same trend as the cadaveric data. Specimens with higher bone mineral density (BMD) were stiffer and the maximum load to failure increased from Group 1 to Group 3. The T8 (Figure 3) and T9 (Figure 4) endplate stresses were reduced by 20% and 33%, respectively in Group 3. The stresses observed at the supraspinous (SSL) and interspinous ligaments (ISL) in Group 3 were higher at T6-T9 as vs. Groups 1 and 2. At T9-T10, the stresses observed in the SSL and ISL in Group 3 were lower as compared to Groups 1 and 2.

CONCLUSIONS

There was a significant reduction in VCFs in those specimens treated with a tapered dose of vertebral cement in the UIV, UIV + 1, and UIV + 2 (Group 3) as compared to spines treated with instrumentation only (Group 1), and those treated with the same amount of cement at the UIV and the UIV + 1 (Group 2). This tapering technique of cement increases the load required for failure decreasing the risk of VCF, the precursor of PJK.

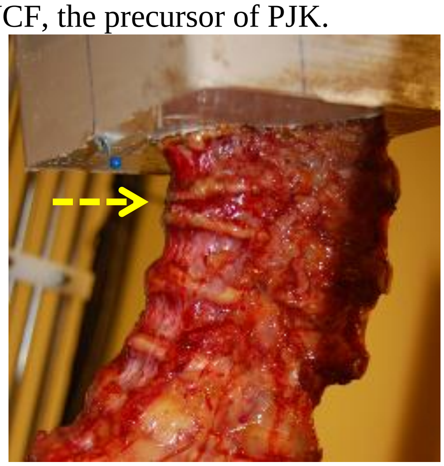

Figure 1: Failure observed in the anterior column (T8) during compressive loading of a specimen in Group 1.

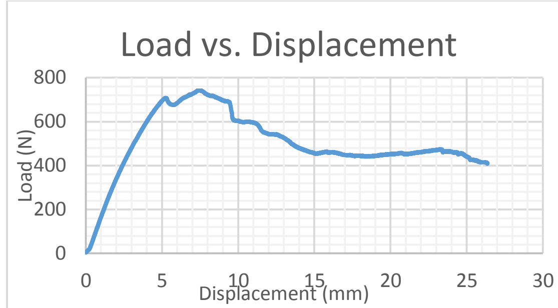

Figure 2: Load vs. displacement plot of a specimen exhibiting an inflection point (peak) indicating the failure load.

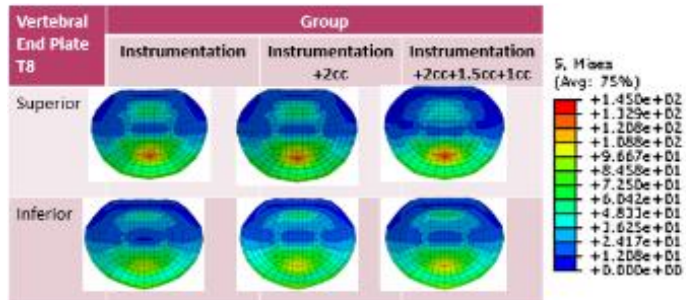

Figure 3: T8 endplate stresses

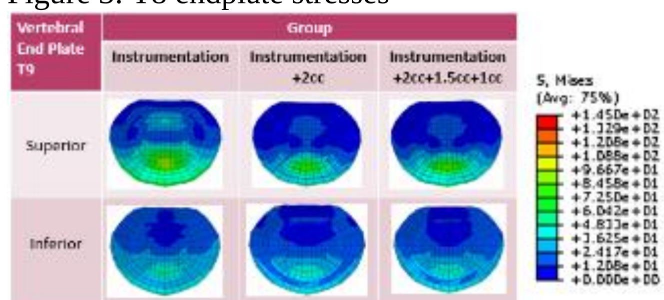

Figure 4: T9 endplate stresses

In both cadaveric and FEA models, this novel technique of using the tapering dose of prophylactic vertebroplasty cement in the UIV, UIV + 1, UIV + 2 decreased the endplate stresses, increased the load required for failure, and reduced the incidence of VCFs above long-segment instrumented constructs. Clinically, this technique may reduce the risk of PJK and PJF. Further biomechanical and clinical analyses are required.

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