Biomechanical Analysis of Intervertebral Cement Extravasation in Vertebral Motion Segments

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abstract

Kyphoplasty is a therapeutic option for pain relief in the setting of compression fractures. Cement extravasation into adjacent disks is a common occurrence. The biomechanical and clinical consequences of cement in the disks currently are unknown. This study investigated the biomechanical effects of cement extravasation into the intervertebral disk in a human cadaveric model. Seven thoracolumbar and lumbar embalmed human cadaveric motion segments were evaluated in axial rotation, right and left lateral bending, and flexion and extension. Stiffness was calculated at baseline and following injection of 1 mL of cement into the intervertebral disk. There was a 13.4% (P=.041) increase in stiffness in axial rotation compared with preinjection motion segments. No significant difference was observed in lateral bending or flexion and extension. In this model, cement extravasation into the disk space increased stiffness in axial rotation. [Orthopedics. 2017; 40(2):e300-e304.]

Compliance fractures secondary to osteoporosis and pathologic etiology are prevalent worldwide, affecting 1.4 million people per year. Initial nonoperative treatment includes bracing and activity restriction and is frequently successful. However, bracing is not without consequences, including prolonged immobilization, brace intolerance, skin breakdown, and pulmonary compromise.

Patients who fail nonoperative treatment may benefit from operative management, including balloon kyphoplasty. Kyphoplasty has been shown to be beneficial in pain resolution secondary to compression fractures. In addition, kyphoplasty is a relatively safe procedure with low complication rates. However, complications from cement extravasation have been reported and include embolization into the lungs and other organs as well as neurologic injury. This study analyzed the biomechanical consequences of cement extravasation into the intervertebral disk using a cadaveric model. The study hypothesis was that cement extravasation into the intervertebral disk would increase relative stiffness in axial rotation, lateral bending, and flexion and extension.

MATERIALS AND METHODS

Specimens

Seven embalmed human cadaveric vertebral specimens were dissected of excess soft tissue to a final specimen, which included the vertebral body with all ligamentous and bony structures, intervertebral disk, and an adjacent vertebral body (constituting a vertebral motion segment). These specimens included three T12-L1, three L2-L3, and one L4-L5 vertebral motion segments. Other specimens were rejected because the vertebral body was insufficient to immobilize in cement or ligamentous structures were missing. Specimens were stored at -20°C until testing. After thawing, the specimens were
potted to the mid-body of each vertebra in a 4 × 4-inch polyvinyl chloride endcap using polymethylmethacrylate cement.

Biomechanical Testing

Potted specimens were clamped in a mechanical testing system (Instron 8511.20; Instron, Norwood, Massachusetts) that allowed displacement-controlled loading through the intervertebral disk (Figure 1). The specimens were tested in flexion and extension, lateral bending, and axial rotation. The following sequence of testing was performed with each specimen:

1. A standardized axial compressive load of 50 N was placed on the specimen via a 6-degree-of-freedom load cell (JR3 Inc, Woodland, California). The clamps were locked on the end caps to secure the specimens in the load plates.

2. A warm-up sequence was performed on each specimen in flexion and extension with 1° of motion performed at 0.25 Hz for 25 cycles. Testing then began with 10 cycles at 0.25 Hz of 3° of motion in both directions for a total of 6° of motion. Angular displacement and torque were recorded. The testing sequence was repeated, and an average precementation stiffness for flexion and extension was calculated from the middle 4 intervals of each trial.

3. The initial load placed on the specimen then was rechecked to confirm no change in the system. After confirmation, the axial rotation sequence was begun. The specimen was rotated 3° in both clockwise and counterclockwise directions at 0.25 Hz for 10 cycles. Angular displacement and torque were recorded, and stiffness was calculated. This test was repeated and averaged. This completed precementation testing.

4. The motion segment then was rotated in the Instron to allow for testing in lateral bending. The standardized load, as described previously, again was placed on the specimen. Three degrees of lateral bending, left and right, was performed at 0.25 Hz for 10 cycles. Angular displacement and torque were recorded, and stiffness was calculated. This test was repeated and averaged. This completed precementation testing.

5. Cementation testing began by determining the center of the specimen, looking anteriorly. This site was marked with an indelible pen. A Kyphon balloon kyphoplasty kit (Medtronic, Minneapolis, Minnesota) was opened, and a full batch of cement was made according to the provided instructions. Using the provided syringe and an 18-gauge needle placed 2 cm deep, 1 mL of cement was injected anterior to posterior in the previously marked location through the anterior longitudinal ligament. The specimens were returned to the refrigerator for short-term storage. The cement was allowed to harden for 24 to 48 hours prior to retesting.

6. After the cement cured, the specimen was tested again in the exact sequence as described for precementation testing. Each specimen was tested 2 consecutive times.

Data Processing and Statistical Analysis

Angular displacement and torque were recorded during each trial. The rotational stiffness was calculated using the average torque change over the middle 4 cycles of each trial (Figures 2-3). The percent change between each sample’s pre- and postcementing stiffness measurements was calculated along with the means and standard deviations of the stiffness changes within each motion. The percent change in sample stiffness was used rather than absolute change to control for the variation of inter-specimen characteristics and allow for more direct comparison between motions. After verifying the data were approximately normally distributed, the stiffness changes in each motion were assessed using Student t test. The null hypothesis was that there would be no change in stiffness after cementing. The level of significance was set at α=0.05. Data analysis was performed using MATLAB (MathWorks, Natick, Massachusetts), and statistical analysis was performed using R (R Foundation for Statistical Computing, Vienna, Austria).

RESULTS

Before proceeding with t tests to analyze the data, the normality of each data set was assessed with the Shapiro-Wilk normality test, using an alternative hypothesis that the data were non-normal. For the axial, flexion and extension, and lateral bending data sets, P values were .64, .62, and .35, respectively. This indicates the null hypothesis that the data are...
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Stiffness \[\left(\frac{\text{in} - \text{lbs}}{\text{degree} (\circ)}\right) = \frac{\tau_{\text{max}} - \tau_{\text{min}}}{6^\circ}\]

Figure 2: Equation for calculating rotational stiffness.

Figure 3: Graph showing torque vs angular displacement.

normally distributed cannot be rejected, hence allowing normality to be assumed. Data are summarized in Figure 4.

The stiffness values before and after cementing for each motion are summarized in the Table as well as the average percent change within each sample. Overall, stiffness tended to increase after cementing. There was a statistically significant increase in a sample’s stiffness in axial rotation (13.4%, \(P=.041\)). The stiffness increase observed in flexion and extension trended toward significance (12.9%, \(P=.079\)). No appreciable difference in stiffness was observed in lateral bending (1.9%, \(P=.711\)).

DISCUSSION

Cement extravasation into the intervertebral disk is a common occurrence with kyphoplasty. The results of this study demonstrate that cement extravasation, as represented by cement injection into the vertebral disk, results in increased stiffness, particularly in axial rotation. There was no difference in lateral bending, and there was trending to a difference in flexion and extension. Cement injected via a single, direct anterior approach resulted in a centrally focused cement ball that minimized stiffness changes in lateral bending and to some extent in flexion and extension. However, cement extravasation in vivo does not necessarily occur in a central location, depending primarily on the location of end plate disruption. Because of this, it is likely that stiffness potentially could increase in all planes in vivo. Injection of cement anteriorly, posteriorly, or laterally would be more likely to affect stiffness in bending forward, backward, and laterally, respectively.

The clinical consequences of this increased stiffness are unknown. Adjacent level fractures following kyphoplasty have been reported.\(^{18-28}\) The etiology for these fractures has been hypothesized as increased stiffness in the cemented vertebral body. Although cement extravasation into the intervertebral disk may increase the likelihood of these fractures, any con-

Figure 4: Graphs showing stiffness increase after cement extravasation for axial rotation, flexion and extension, and lateral bending.
Conclusion to this extent is beyond the scope of this study and warrants further investigation.

Limitations of this study include the small sample size and replicability of the cement extravasation in vivo. Comparison of thoracolumbar and lower lumbar segments was prevented by limited sample availability, and considering the anatomic differences between these 2 sites, a comparative investigation into the consequences of cement extravasation is warranted.

In addition, the process of embalming has been shown to change the mechanical properties of specimens. Although the use of fresh-frozen specimens may be ideal, the limitations in using embalmed specimens were minimized by studying the percent change within a given specimen rather than studying absolute values. Finally, the centrally placed cement limited the evaluation of mechanical changes in lateral bending as well as forward flexion and extension, as would be seen in vivo.

A central location was used to allow for ideal standardization between segments. Centrally placed cement in the vertebral body via a direct anterior injection is a surrogate for the bipedicular placement of cement with subsequent cement extravasation through the vertebral end plate into the intervertebral disk. Because there is no standard location of cement extravasation in vivo, it cannot be replicated exactly.

**Conclusion**

Kyphoplasty is a common treatment for compression fractures. Cement extravasation can occur and is associated with significant medical consequences. Extravasation can occur through the end plate of the fractured vertebral body with unknown clinical effect. This study evaluated the biomechanical repercussions of cement extravasation into the center of an embalmed intervertebral disk. The findings showed increased stiffness in axial rotation with no significant increase in bending stiffness.

**REFERENCES**


