INTRODUCTION: Approximately 260,000 patients with first painful osteoporotic vertebral compression fracture (VCF) are diagnosed annually in the U.S. One-third of the patients develop chronic disabling pain and progressive kyphotic deformity. The change in spinal alignment after VCF is believed to increase the risk of new fractures in the vertebrae above or below. Augmentation of fractured vertebral body with bone cement after percutaneous reduction of the vertebral body deformity using an inflatable bone tamp (balloon kyphoplasty) is becoming a treatment of choice in those patients who have not responded to conventional medical therapy. The treatment goals are to reduce pain by stabilizing the fractured vertebra, and restore normal spinal alignment to reduce the risk of new VCFs in adjacent vertebrae.

The objectives of this study were to (1) measure the effect of thoracic VCFs on segmental kyphosis and the resultant anterior shift of the physiologic compressive load path, and (2) measure the effect of balloon kyphoplasty in restoring the normal spinal alignment and the physiologic compressive load path. The correction of spinal alignment with balloon inflation was investigated under two magnitudes of physiologic compressive preload, with and without a supplemental extension moment.

METHODS: The experimental model consisted of three-vertebra specimens. Six thoracic spines (72 years±12) were used. We developed a new technique for reproducibly creating a VCF in the middle vertebra of the test specimen. It involved disruption of the cancellous bone using an intrapedicular approach, thereby creating a “stress-riser” in the target vertebra. Under fluoroscopic control a channel was created through each pedicle and a balloon was inserted. The trabecular bone was disrupted by inflating the balloons. The specimen was loaded in compression using bilateral loading cables that passed through cable guides in the proximal and distal vertebrae of the specimen (Fig. 1a). The compressive load was increased until a fracture was observed on fluoroscopy with the loss of the anterior vertebral height =25% of the initial height (Fig. 1b). Digital video-fluoroscopic (VF) images were acquired to document the spinal alignment before fracture and after fracture under a physiologic load of 250 N. The loading cables, coated with radiopaque barium, were visible on all radiographs.

Correction of the VCF deformity was performed using inflatable balloons inserted into the vertebra through the intrapedicular channels. The change in spinal alignment, the balloon inflation pressure, and the volume of contrast were monitored under four conditions: (i) balloon inflation with the specimen maintained under a physiologic compressive preload of 250 N, (ii) supplemental extension with the inflated balloon in place and a preload of 250 N, (iii) balloon inflation with the specimen maintained under a physiologic compressive preload of 150 N (Fig. 1c), and (iv) supplemental extension with the inflated balloon in place and a preload of 150 N (Fig. 1d).

The alterations in spinal alignment were quantified by measuring the following variables (Fig. 1a-d): anterior vertebral height (H) of the middle vertebra (VCF level), segmental kyphosis angle (S), and shift of the compressive load path (d). The measurements were performed on VF images by three observers and averaged. The data were analyzed using repeated-measures ANOVA with Bonferroni correction for multiple comparisons.

RESULTS: The VCF caused significant changes in the pre-fracture spinal alignment (p<0.05). The anterior vertebral body height loss was 11 mm (SD: 2.2). The segmental kyphosis (S) increased by 11 degrees (SD: 4.3). The compressive load path shifted anteriorly by 5.2 mm (SD: 0.5) in the fractured vertebra, and by 4.4 mm (SD: 0.9) and 3.4 mm (SD: 1.6) in the upper and lower vertebrae, respectively.

Balloon inflation significantly reduced the VCF deformity under both compressive preload magnitudes (150 N and 250 N) (p<0.05). At the 250 N preload, the anterior height correction was 8.3 mm (SD: 0.9) and the segmental kyphosis angle (S) corrected by 8.3 degrees (SD: 3.3). A decrease in compressive preload further increased the anterior vertebral body height by 2.4 mm (SD:0.8), and improved the kyphosis correction by 3 degrees (SD: 0.5) (p<0.05).

Balloon inflation under both compressive preload magnitudes shifted the compressive load path posteriorly relative to the fractured state in the upper, middle, and lower vertebrae by 2.6 mm±1.5, 2.8 mm±0.8, and 1.8 mm±1.1, respectively (p<0.05). The difference in the load path between the pre-fracture and post-correction states was not statistically significant (p>0.05).

Supplemental extension with the inflated balloon in place had a significant positive effect in correcting all measures of spinal alignment (VCF deformity and load path) under both compressive preload magnitudes (p<0.05).

DISCUSSION: Correction of VCF deformity with balloon kyphoplasty has been investigated in the literature using single vertebrae; however, its effect on the angular alignment of adjacent segments has not been reported under physiologic compressive loads. Further, the effects of VCF and its correction on the changes in the path of the physiologic compressive load have not been investigated.

The present study simulated the correction of recent vertebral fractures. Balloon inflation significantly reduced the VCF angular deformity under physiologic compressive loads and shifted the compressive load path posteriorly relative to the fractured state, approaching the pre-fracture alignment. Finally, supplemental extension was useful in augmenting the correction achieved using balloon inflation alone and in restoring the pre-fracture alignment.

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