A Biomechanical Model Simulating Vertebral Compression Fracture and Proximal Junctional Kyphosis

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Introduction: Junctional kyphosis is a common radiographic finding following posterior instrumented fusion. Proximal junctional kyphosis (PJK) is defined as a sagittal Cobb angle of >10° and at least 10° greater than the preoperative Cobb angle [1]. The angle is measured between the caudal endplate of the upper instrumented vertebra and the cephalad endplate of the vertebra 2 levels superior [1]. Its prevalence at 2-year follow-up after posterior fusion has been cited as high as 46% [2]. Furthermore, vertebral compression fractures (VCF) have been associated with some incidents of PJK [3], and a 15% decrease in vertebral body height is considered indicative of vertebral compression fracture [4]. Although different types of instrumentation have been reported to result in lower incidences of PKJ [5], no biomechanical testing has validated these reports. No biomechanical model currently exists to replicate PJK and accurately evaluate proposed strategies to prevent it. We hypothesize that a combination of compression, posterioanterior shear, and flexion moment will replicate the progression of kyphosis. The goals of this study are to develop a biomechanical model that accurately replicates the PJK seen following posterior instrumented fusion and to correlate increasing sagittal Cobb angle with decreasing vertebral body height.

Methods: To generate compressive force, posterioanterior shear, and flexion moment, a custom fixture was fabricated (Figure 1). The fixture included an adjustable angle slider plate and an adjustable moment arm. Adjustment of the angle of the slider plate controlled the magnitude of the shear force, and adjustment of the moment arm controlled the magnitude of the flexion moment. One cadaveric specimen (spinal levels T12-L2, 49 year old male, 75 inches, 171 pounds) underwent preliminary fatigue testing with this fixture for 20,000 cycles. Using a servohydraulic testframe (Instron 8521), a compressive load with a mean of 330N and a maximum of 600N was applied at a frequency of 1.0 Hz. The angle of the slider plate was set to 8.5 degrees, resulting in posterioanterior shear with a magnitude of 89 N. The moment arm was set to 117mm, resulting in a flexion moment of 25Nm. A sagittal x-ray was taken before testing began and every 1000 cycles thereafter (Philips BV Pulsera C-Arm). The x-ray images were analyzed in RadiAnt DICOM Viewer (Medixant 2014, Poznan, Poland). They were analyzed for changes in sagittal Cobb angle and loss of height of the vertebral body. The Cobb angle was measured between the inferior endplate of L2 and the superior endplate of T12. Height of the vertebral body was measured at the anterior aspect of L1 along a line perpendicular to the caudal endplate of L1. Rates of progression of kyphosis and compression fracture were monitored and analyzed for statistically significant correlations. Further tests are ongoing to validate the model.
Results: The rate of progression of compression fractures and the rate of progression of kyphosis were analyzed for statistically significant correlations with the number of cycles and with one another. The total change in anterior height of the vertebral body was 4.4% of the original height, and it progressed at approximately 1% per 4,500 cycles. Diagnostic criteria for VCF (15% reduction in height) was not achieved within the 20,000 cycles in this test, but following the trend seen in this study, a 15% reduction would be expected within 70,000 cycles. The total change in Cobb angle at the proximal junction was 7.5° (increase in sagittal Cobb angle of >10° study, but following the trend seen in this study, a 10°, and it progressed at approximately 1° per 2700 cycles. Diagnostic criteria for PJK change would be expected within 27,000 cycles was not reached in this study.

Discussion: Results from this study indicate that loss of vertebral height and increase in sagittal Cobb angle can be replicated using a combination of compression, posterioanterior shear, and flexion moment. Loss of vertebral height and increasing sagittal Cobb angle progressed linearly, and their rates of progression were statistically significantly correlated to the number of cycles, as well as to one another. Therefore, it can be concluded that use of the same fixture and loading for an increased number of cycles would produce diagnostic criteria for PJK and VCF.

Significance: Future studies will increase cycle count until a 15% decrease in vertebral height and a 10° Cobb angle have been observed, and replicate the results in increase in sagittal Cobb angle have been observed, and replicate the results in multiple cadaver specimens.