INTRODUCTION
Wedge fractures, the most common type of osteoporotic spine fracture [1], are thought to be associated with forward flexion loading. Despite an emerging understanding of failure mechanisms of the vertebral body for compression loading [2], the micromechanics of vertebral failure for forward flexion remains unexplored. In this study, we sought to use finite element analysis of micro-CT scans to compare internal stresses, at the trabecular tissue level, in human vertebrae virtually subjected to compression and forward flexion loading. This study is unique since it is the first to explore the micro-mechanics of flexion type loading within the vertebral body, using such high-resolution computational techniques.

METHODS
Analyses were performed on micro-CT images of 22 human T9 vertebral bodies (mean ± SD age = 81.5 ± 9.6 years; 11 male, 11 female). Finite element models were made directly from the images, using 60 μm sized cube-shaped finite elements [3]. Each resulting finite element model had up to 80 million elements and over 300 million degrees of freedom. Two loading conditions were investigated for each vertebra, for a total of 44 analyses. For compression loading, a uniform apparent compressive strain of 1% was applied to the top surface of each model through a simulated intervertebral disc (isotropic Young’s modulus = 8 MPa; Poisson’s ratio = 0.45); for forward flexion, a forward bending angle of 5° was applied, pivoting about the most posterior aspect of the top of the disc. To assess failure mechanisms, a tissue-level risk factor was calculated for each element, based on the higher absolute value of the ratio of maximum (or minimum) principal strain to the assumed tensile (0.33%) or compressive (-0.81%) yield strain [4]. Elements were ranked by this tissue-level risk factor, and the top 10% of these elements represented the “high-risk” tissue. Results are presented as mean values (± SD), averaged over the 22 vertebrae.

RESULTS
Compared to uniform compression, forward bending shifted the high-risk tissue towards the anterior aspect of the vertebral body — but the extent of this shift was only modest. Visual analysis indicated that the high-risk tissue was focused in the central regions of the trabecular bone and endplates regardless of the loading conditions (Fig. 1). Quantitative analysis confirmed these trends, the flexion causing only slight shifts in how the high-risk tissue was distributed across the different compartments (Fig. 2). Analysis of the distribution of the high-risk tissue in the anterior-posterior direction confirmed these trends, demonstrating only subtle anterior shifts with forward flexion (Fig. 3).

DISCUSSION
These results suggest that, regardless of uniform compression or forward flexion, the bone tissue in and close to the central trabecular bone and endplates of the human vertebral body is at the highest risk of initial failure. Thus, with compliant discs, it appears that the applied loads on the vertebra are effectively distributed so that the regions of high-risk tissue in the vertebral body are relatively insensitive to whether the vertebrae is loaded in uniform compression or forward flexion.

SIGNIFICANCE
Wedge fractures cannot be explained simply as a response to forward flexion since stresses within the vertebral body are relatively insensitive to compression vs. flexion. Thus, factors other than loading conditions must influence the etiology of osteoporotic wedge fractures.

REFERENCES