Evaluation of Pedicle Screw Augmentation and Trajectory Using Loading Protocol That Simulates In Vivo Combinations of Pullout, Migration and Toggle

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INTRODUCTION:
Pedicle screw-bone interface failure in posterior spinal constructs clinically results in combinations of screw pull out, migration, and toggle within the vertebral body. Our objective was to develop a biomechanical testing protocol to simulate loading that could produce combinations of clinically observed failure modes to evaluate the effects of screw trajectory with and without cement augmentation in osteoporotic bone.

MATERIALS AND METHODS:
A pushrod-yoke fixture was developed to apply a force to the vertebral body to be able to simulate combinations of screw-bone interface loading with a desired flexion-extension moment. Pedicle screws were inserted into osteoporotic (mean BMD=0.521 g/cc) cadaveric thoracolumbar vertebrae (without and with 2ml cement augmentation consistent with surgical practice) with one of two screw trajectories (0° or 20° relative to the superior endplate; fig 2). Alternating, between 0° and 20°, contralateral pedicles were used for an intra-specimen control. 20° was chosen as a consistent screw trajectory which placed the tip of the screw against the superior endplate prior to failure testing. Equal pull out (AP) and transverse (axial) components of force were applied to the vertebral body at an AP distance equivalent to the center of the vertebral body (thus no external applied flexion-extension moment at that location). This was done to reproduce expected in vivo loading of instrumented vertebra having up to 45° sagittal plane orientation in the lower lumbar and upper thoracic spine. Ten non-augmented samples and ten samples augmented with calcium phosphate (Hydroset, Stryker Spine) at each screw trajectory were constructed and loaded (in single cycle position control) to failure (onset of irreversible bone damage along the screw-bone interface). An optical tracking system was used to quantitatively measure the relative 3D motion of the pedicle screw relative to the vertebral bone at three points on the screw’s axis (posterior entry site, center of pedicle, and tip), and its sagittal plane angular toggle.

RESULTS:
Failure loads were observed to depend upon screw trajectory relative to the superior endplates. Initial failure was result of screw toggle (different magnitude of sagittal plane migration of the points along the screw) followed by onset of screw pull out for both non- and augmented specimen. Initial failure was significantly higher (p<0.05) for augmented compared to the non-augmented samples (fig 3). Initial failure was also significantly higher (p<0.05) for non- and augmented samples inserted with 20° angle, relative to the superior endplate, as compared to control samples of non- and augmented samples with a trajectory of 0° relative to the superior endplate (fig 3).

DISCUSSION:
It was observed during testing that samples inserted at a trajectory of 0° relative to the superior endplate exhibited a “secondary failure”. This “secondary failure” occurred subsequent to a nearly linear behavior of the force vs. displacement curve until initial failure was observed. Subsequent to the initial failure, the load increased a second time up to ultimate failure of the specimen. It was determined that the initial failure occurred as the bone-screw interface failed. The secondary loading began as the screw tip contacted the superior endplate and thus could again support additional load up to a “secondary failure”. Screws inserted with a trajectory of 20° relative to the superior endplate were already resting against the superior endplate, and thus a “secondary failure” was not observed in these samples. This behavior is expected to have clinical significance as the screws inserted at 0° in osteoporotic vertebra have a tendency to fail at a significantly lower load than screws inserted at 20° relative to the superior endplate.

The equal force component zero moment at center of vertebra loading protocol in our study with the fixtures developed produced combined screw toggle-migration and pullout similar in appearance to that observed in clinical cases. We believe that the fixtures allow combined load component testing protocols that produce more realistic simulation of in vivo screw-bone interface loading, and thus the potential to identify the important parameters that need to be controlled to improve strength of pedicle screw foundations in osteoporotic bone.

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