• Compressive Stiffness and Bilateral Intra-Annular Stresses after Spinal Hemiepiphysiodesis
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Introduction: Spinal growth modification methods affect the distribution of static and dynamic compressive stresses in the disc and vertebral growth plate. Defining initial post-operative changes is important to the timing of differential growth and possible side effects to the disc. These changes likely depend strongly on device design, so characterization of biomechanical effects for each type of construct is necessary to understand differences in potential efficacies.

In previous reports on spinal hemiepiphysiodesis, growth was shown to be modified asymmetrically over time by changes to the structure of the vertebral growth plate using a staple-like implant that unilaterally restricted joint displacement. Initial postoperative stiffness changes were reported in side bending and flexion-extension. In addition, bilateral stresses in the annulus were reported in axial compression. However, the latter results showed differences from ipsilateral to contralateral sides in both control and stapled conditions, which suggested that in vitro test conditions may not have sufficiently simulated physiological constraints. Therefore, neither the compressive load-displacement behavior nor a stress gradient under axial compression has yet been reported. The purpose of this study was to define the initial post-operative effects of hemiepiphysial stapling on motion segment load-displacement behavior in compression, and on baseline static and peak dynamic bilateral annular compressive stresses.

Methods: Biomechanical tests were conducted on spine motion segments from normal, skeletally immature pigs (approved by IACUC). Each segment was tested before and after insertion of a stainless steel implant. Structural properties of the intervertebral joint were defined from load-displacement curves. Static and dynamic compressive stresses were determined bilaterally using custom, intra-annular, MEMS-based stress sensors. These sensors were developed and used by the investigators in previous in vivo tests.

Prior to testing, five thoracic spines were harvested from female domestic pigs, 195-340 N (20-35 kg). Four motion segments were dissected from each spine (T4-5, T6-7, T8-9, and T10-11). Simulated physiological motions and loads were allowed by custom 5-degree-of-freedom fixtures, which allowed for both realignment of the motion segment after stapling and for motion of the distal vertebra during loading. Five cycles of axial compressive displacements were applied at a constant rate (10 mm/min) from slight tension to 0.8 mm compression, corresponding to joint loads of approximately -5 N to 400 N. Compressive stresses were measured on left and right sides using custom sensors placed within the disc annulus. Stresses were measured during staple insertion and subsequent stress relaxation, and during compression tests. Stress sensors were sampled simultaneously with joint load and displacement using a telemetry and data acquisition system (Agile-Link v1.3.9, MicroStrain, Inc., Williston, VT). Peak load (L_peak), tangent stiffness (K_tan), displacement at initiation of loading (L_0), and peak stress (σ_peak) were determined from the fifth cycle. Differences due to stapling were defined with paired t-tests.

Stress-time histories were used to compare changes in baseline and peak compressive stresses through the intervertebral disc, both by side (ipsilateral vs. contralateral) and by treatment (control vs. stapled) conditions. The change in static baseline stresses were determined by comparing the stresses before staple insertion to the stresses measured 2 minutes following staple implantation, after stress relaxation.

Results: The overall, secant, compressive stiffness increased, by means of a decrease in the displacement at load initiation (24%, p<0.02) after staple insertion. Tangent stiffness decreased by 6% (p<0.02) after stapling. Compressive stresses increased during the insertion of the staple, but then relaxed to zero at equilibrium, so that the baseline static stress was not changed. Mean peak cyclic stresses decreased by 20% after stapling.

Discussion: Stapling effects on initial post-operative axial compressive biomechanical properties of the intervertebral joint, while sufficient to alter growth over time, were relatively mild compared to joint immobilization. Limitations include high variability in stresses due to sensor design and packaging, sensitivity of stresses to test constraints, and sensor size and location. Biological disc changes after chronic implantation remain to be defined. However, relatively small changes after treatment suggest that the disc may be less severely affected by this type of implant compared to immobilization.


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