The Effects of Annular Compromise on Lumbar Spine Flexion/Extension Stiffness and Damping: An In-vitro Investigation

John M. Popovich, Jr., PhD, DPT, Robert L. Zondervan, MA, Vilok Vijayanagar, BS, Mamikon B. Gukasov, BS, N. Peter Reeves, PhD. Michigan State University, Center for Orthopedic Research, College of Osteopathic Medicine, East Lansing, MI, USA.


Introduction: Annular lesions have been shown to demonstrate significant changes in the mechanics of the lumbar spine, such as increased range of motion, decreased spinal stiffness and increased neutral zone. These mechanical changes are important to understand the clinical consequences linked to intervertebral disc injuries; however, the testing methods by which they have been previously derived may not fully describe the dynamic behavior of the spine. Crisco and colleagues (2007) developed a pendulum method to quantify the stiffness and damping of a functional spine unit (FSU) of the lumbar spine. The objective of this study was to determine the effects of experimentally induced annular compromise on stiffness and damping of the porcine lumbar FSU. We hypothesized that stiffness and damping would decrease following annular compromise.

Methods: Six fresh frozen porcine lumbar FSUs, free of any gross morphologic deformity or pathology, were dissected leaving only the osteoligamentous spine. Wood screws were inserted into the cranial and caudal vertebra of the FSU to assist in anchoring the specimen in two-part polyurethane potting solution. Specimens were submerged into the potting solution at the level of the vertebrae midline, parallel to the corresponding intervertebral disc. Specimens were stored at -20°C prior to biomechanical testing in a custom-made pendulum apparatus, modified from Crisco et al. (2007). Potted specimens were thawed at room temperature overnight and submersed in a saline bath for biomechanical testing. The caudal segment was securely mounted to the bath and the cranial end was secured to the pendulum arm. As part of another study protocol, an axial compressive load of 45.5 kg (100 lb) was applied to the pendulum arm and the specimen was then tested three times every fifteen minutes for three hours. A test trial consisted of pulling the pendulum into 5° of flexion and releasing it, allowing the spine to oscillate unconstrained. After the three hours of testing, each FSU was tested through successive loading and unloading using weight-sets of 22.7, 45.5, 68.2, 90.9, 68.2, 45.5, and 22.7 kg. Each weight-set was tested three times; allowing one minute between each test trial and three minutes between each weight-set. Immediately following the final weight-set (22.7 kg), the annulus fibrosus was compromised by inducing an anterior stab injury. This injury was induced by vertically incising the annulus fibrosus anteriorly, just lateral to the anterior longitudinal ligament. The FSU was tested again at the 22.7 kg load to allow for a comparison of pre- and post-annular compromise.

Kinematic data corresponding to the FSU were recorded at a sampling rate of 100 Hz (Phoenix Technologies Inc., Burnaby, BC). The kinematic data were used to calculate stiffness and damping as described by Crisco et al. (2007). Stiffness and damping were calculated using the mean of the three test trials for the intact and annular stab injury conditions. A Wilcoxon signed ranks test was performed using SPSS (v. 18, SPSS, Inc., Chicago, IL) to determine differences between the intact and annular stab injury conditions. Statistical significance was set at p≤0.05.

Results: In general, sagittal plane angular displacement increased and took longer to reach equilibrium following annular stab injury (Figure 1). Additionally, stiffness decreased an average of 43% (p=0.028) and damping decreased by an average of 34% (p=0.028) following annular stab injury (Figure 2).
Discussion: This study examined the dynamic behavior of porcine FSUs before and immediately after annular compromise. Similar to other reports, stiffness decreased significantly following the experimentally induced annulus injury. Damping also decreased significantly following injury, however, we are not aware of any previous reports that have investigated the damping characteristics of the spine following acute annular injury. These biomechanical changes were in the direction as hypothesized and result from the altered physical properties of the annulus fibrosus.

Significance: An accurate description of spinal stiffness and damping is essential in understanding the mechanical behavior of the spine. This work will contribute to understanding the dynamic behavior of the intervertebral disc to injury. Such information can be used to develop more accurate biomechanical models incorporating intervertebral disc injury and for the development and design of orthopedic interventions aimed at incorporating spinal stiffness and damping characteristics.

Acknowledgments: The authors would like to acknowledge Clark Radcliffe, PhD for his guidance in the mechanical analysis, Kiilani Kaaikala, BS for her assistance in specimen preparation and data collection and Angela Lee, MPH for her assistance in developing data collection software.
