Axial Torsion Alters Load Distribution Among Spinal Components In Flexion/extension In Rabbit Lumbar Spinal Segments

Robert A. Hartman, PhD, Robert T. Tisherman, BS, Kevin M. Bell, PhD, Richard E. Debski, PhD, James D. Kang, MD, Gwendolyn Sowa, MD, PhD.
University of Pittsburgh, Pittsburgh, PA, USA.


Introduction: A majority of spinal disorders underlying pain and neurologic symptoms have been classified as being of mechanical origin arising from anatomical structures including intervertebral discs (IVD), facet joints (FJ), and spinal ligaments [1]. Activities involving repeated combined axial torsion (AT) coupled with flexion/extension (F/E) are associated with increased risk of injury and development of back pain [2]. While a few studies have examined the separate mechanical effects of flexion/extension (F/E) and axial torsion (AT) on individual spinal structures [3-5], the effects of coupled AT on the role of spinal structures in load distribution in F/E remains unstudied experimentally [6]. Experimental descriptions of how spinal components contribute to moment distribution in segmental loading typically involve a serial resection of joint structures with repeated intact kinematics and measurements of changes in moment with each cut. [7,8]. Robotic systems used in joint research can replay intact kinematic motion paths to determine the role of spinal components in 6 DOF loading. Relying on the principle of linear superposition, the percent contribution of each structure to primary moment resistance, % Moment, is defined by the change in primary end-point moment with each cut, i, normalized by the intact moment, Mintact, % Moment= (M(i) - M(i-1))/M(intact) (Eq. 1)
The objective of this study was to quantify how F/E moments and forces were distributed in spinal components of rabbit lumbar FSUs in (i) neutral F/E and (ii) coupled AT with F/E with the goal of describing the effects of AT on the role of key structures in F/E.

Methods: Methods: Fresh/frozen L4-5 NZW rabbit (Female, 10-12 mo.) FSUs were mounted within a robot-based spine testing system as described previously [11]: FSUs (n=4) were subjected to F/E moment targets of 0.5/0.15 Nm in neutral axial positions (neutral F/E) or with coupled axial rotations (AT+F/E) using AT targets of 0.8 Nm. FSUs were cycled three times to moment targets for preconditioning and the third motion path was replayed subsequently. These methods were consistent with previous testing for biological outcomes [12]. After replay of the intact motion path, FSUs were serially resected in a posterior-to-anterior manner. Experimental interventions were performed as follows: the (1) supraspinous and interspinous ligaments (SSL/ISL) were resected, (2) ligamenta flava (LF) were resected, (3) facet capsules and facets cartilage were removed, and (4) discs were punctured antero-laterally with a 16G needle in to the NP. Needle puncture depressurizes discs; however, the needle diameter in rabbit lumbar discs indicates annular damage occurred as well [9]. Nonetheless, depressurization of the NP is predicted to be the primary change resulting from injury [5]. The remaining moment was supported by the anterior column composed primarily of the IVD. For each replayed state,
after waiting five minutes, the robot system replayed intact kinematics three times. Neutral F/E was followed five minutes later by AT+F/E.

Analysis: Measured forces (and moments) are those that act on (or about) the center-of-rotation (COR) in the mid-height, posterior third of the disc. Mean normalized moments and contributions to moment resistance were calculated (Eq. 1). The role of the IVD in moment resistance was defined by summing the punctured state and remaining moments after puncture. Mean changes in force magnitudes with resection were calculated; disc puncture was analyzed as a separate state.

**Results:** In flexion, the LF was the predominant contributor to flexion moment resistance (Figure 1). FSUs subjected to AT+F showed an increased role of the disc in flexion compared to those in neutral flexion. In extension, facets contributed to 10.9±3.4% of the neutral moment. The addition of AT generally increased the role of resected structures to extension resistance; the role of facets (39.72±12.86 %) increased 3.65-fold. Resection of the spinal ligaments in neutral F/E caused little to no change in forces experienced in the disc (Figure 2). The LF played an important role in flexion moment resistance but did not influence forces in the disc. The addition of AT caused an increase in force (~13.1% body weight (BW)) with LF resection. This reflects the lack of pure moment loading with AT and suggests higher overall loading in LF with torsion. Most notably, resection of facets increased force magnitudes in extension (4.77±4.84 and 11.98±3.83 in Neutral F/E and Large AT+F/E, respectively). These changes in force indicate that facets restricted forces in extension. This change in force was >2.5-fold higher with coupled AT. The orientation of the force vector (in order of size) was anterior, lateral and inferior (data not shown). Disc puncture tended to decrease forces (Figure 2) with similar reduction of components in all directions (data not shown).

**Discussion:** This study quantified the mechanical role of important spinal structures in rabbit lumbar FSUs in neutral and axially rotated F/E. It identified the predominant role of the LF in flexion moment resistance and the disc in extension moment resistance. Mechanical studies of human and large animal spines have also identified the prominence of the LF in flexion moment resistance [7,13]; however, in this rabbit study, the contribution of the LF in flexion was higher than in other species [7,13]. The addition of torsion to F/E increased the role of facets in extension moment resistance and increased the forces associated with facet joints in extension. This reflects previous fatigue failure testing findings that showed higher rates of failure in facets following addition of torsion [14]. Thus, combined torsion increases risk of overloading the LF in flexion and facets in extension.

**Significance:** Understanding how combined torsion in flexion/extension affects load distribution among components of the lumbar spine is critical to identifying tissues vulnerable to overloading and possible injury with coupled torsion. This data is also valuable for characterizing spine mechanics in rabbits, popular animal models for therapeutic screening, to compare load distribution in flexion/extension to humans and other species.
ORS 2015 Annual Meeting
Poster No: 0758