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ACUTE THORACIC VERTEBRAL INJURY THRESHOLDS

Mari S. Truman
Robson Lapina Inc., Columbus OH

Lisa A. Ferrara
Robson Lapina Inc., Lancaster PA

Ryan Milks, Illya Gordon and Jason Eckhardt
The Cleveland Clinic Foundation, Cleveland OH

ABSTRACT

This study measures select static and dynamic characteristics of the human mid-thoracic spine, and compares them to previously published data for the thoraco-lumbar and cervical regions. Little information is available on the acute injury threshold for mid-thoracic intervertebral discs. The aim of this study was to characterize injury thresholds for the thoracic spine. Non-destructive combined flexion-compression loading experiments were conducted on 5 fresh human T5-T10 functional spinal units (FSU) at quasi-static and physiologic strain rates, and the resulting load-deflection responses were converted into global and local stiffness. Subsequently, 29 thoracic vertebrae (T5-T10) from 6 spines were subjected to moderate to severe impact loading in flexion. The peak forces and pressures were not statistically different between the thoracic disc levels. However, the mean injury forces and pressures were statistically different from mean failure forces found in the literature for both the lumbar and cervical spine regions, with the thoracic values falling between the cervical and lumbar values.

INTRODUCTION

Little information exists pertaining to the dynamic response of the thoracic vertebral and intervertebral discs. Therefore, the objective of this study was to evaluate the effect of dynamic loading, compression and flexion stiffness was measured at increasing load rates for each FSU. The methods used in the dynamic injury simulation reflect our intent to capture the injury forces and energy absorption properties of individual thoracic disc-endplate-body segments, as opposed to the whole FSU.

MATERIALS AND METHODS

Six unembalmed, thawed, saline-soaked human mid-thoracic spine (T5-T10) structures were biomechanically tested. Ages ranged from 39 to 68 years, mean of 44 (+/-11.9) years. Each thoracic vertebral body was DEXA (dual energy x-ray absorptiometry) scanned to determine the bone mineral density. Scanning revealed five osteopenic and one normal spine (mean BMD .884 (+/- .096). 5 of the 6 thoracic spines underwent compressive and flexion stiffness testing. In addition, 3 of the spines exhibited grade 0 or 1 disc degeneration, and the remaining were grades 2 or 3. The surrounding musculature was removed from each spine leaving all ligamentous structures intact. The upper and lower vertebrae were each embedded to square brackets using a polyester resin and bone screws. The brackets were sized to fit custom grips for the materials testing apparatus (MTS Alliance RT/10, MTS Corp., Eden Prairie, MN) which housed a rotational potentiometer. The rotation of the upper and lower gripping fixtures were constantly monitored with rotational potentiometers for continuous measurement of angular rotations during dynamic loading of each specimen. Potting was mid-body or less assuring that end discs and facet joints were unencumbered with embedding material. Motion pins with two spherical balls were applied to each vertebral body, and digital movies of the spine segments were taken to facilitate calculation of the relative stiffness of each intervertebral joint segment.

Stiffness Evaluation: Each specimen's initial center of rotation was established by applying a 100N maximum compressive load to the upper jig. The position was adjusted and load reapplied until no significant specimen rotation (>1 degree) was detected by the potentiometers. During compression testing, the mounting fixtures were locked to allow for pure compression. For flexion loading, specimens were shifted dorsally in the fixtures 2 cm from the previously established center of rotation. Specimens were loaded non-destructively for 9 cycles in stroke control to 500 N and then unloaded to 25 N for 9 cycles at rates of .2, 2 and 5 mm/min (in sequence). The mean was calculated for the last 3 cycles of loading. Load-displacement data was collected at a sampling rate of 0.5 kHz. Following stiffness testing, specimens were prepared for impact evaluation

Impact Evaluation – Dynamic Offset Compression: Six mid-thoracic spinal FSU's were subsequently prepared for impact testing. The posterior elements were removed and the specimens were dissected mid-vertebral body into individual disc motion segments

(T5-6, T6-7, T7-8 and T9-10) and prepared for mechanical testing, leaving the ALL and PLL ligamentous structures and discs intact. The upper and lower vertebral ends were embedded in 8.9 cm diameter discs of low melt temperature metal alloy (bismuth-lead-tin-cadmium, Cerro metal Products Co., Bellefonte PA). The discs, endplates, and at least 6 mm of each vertebral body were free of embedding material. These fixtures applied a compressive preload between 2 and 4.4 N. A drop test apparatus was used to apply dynamic loads.

The impact head was dropped .305 m, resulting a dynamic load rate of 2.44 ms^{-1}. The mass of the impact head was adjusted to apply energies of 30.5 J to 21 specimens and 44 J to 8 specimens. These load rates and energies are similar to those applied by Osvalder et al [1] for dynamic flexion-shear loading of the lumbar spine (1.6 ms^{-1} and 26 J ; 2.1 m/s and 44J). Statistical analyses incorporated a Linear regression analysis to establish the significance of the relationship between peak pressures and BMD , a T-test with 2-tailed P values was used to compare the peak forces and pressures achieved with the impact energies , a Wilcoxon's signed ranked test was used when comparing results to specific means found in the literature, and a one-way Anova to evaluate the possible difference in force and pressure levels by disc level.

RESULTS - STIFFNESS

The dynamic response (5 mm/s) averaged 162% stiffer than the quasi-static response (.2 mm/s). An increase from.2mm/s to 2 mm/s resulted in an average 56% increase. These differences were statistically significant (p<.0001). Voo et al [2] showed a similar trend in the cervical spine.

Figure 1 - Thoracic FSU Compressive Stiffness

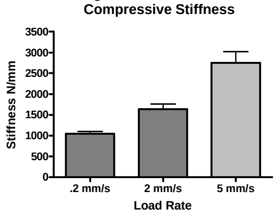


Figure 2 - Thoracic FSU Flexion Stiffness

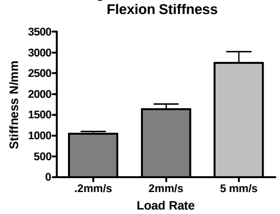


Figure 3 - Injury Force Gr 0-1 vs Gr 2-3

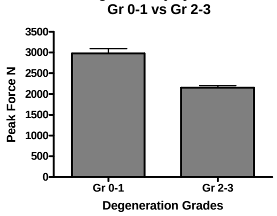
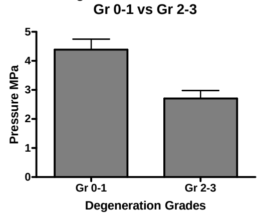


Figure 4 - Ave. Pressure Gr 0-1 vs Gr 2-3



RESULTS - DYNAMIC COMPRESSION/FLEXION

Mean injury force at 30.5 J is 2248 ± 74.30 N=17. At 44 J the mean is 3078 ± 160.5 N=8. The difference between means is -829.8 ± 153. This 44% increase in energy (30.5 to 44 J) resulted in 37% increase in mean peak force. (Statistically significant difference - Student's t-test., P<.0001.) Peak forces and pressures measured were strongly dependant on spine health status. Differences between individual FSU's were significant. (1-way Anova, P $\leq$.0316) The mean injury forces and pressures for grades 0-1 disc degeneration were 38% higher than grades 2-3 (P$\leq$.001). Peak thoracic injury forces are also higher than the cervical injury forces reported by McElhaney [3] and Nahum [4]. (Wilcoxon signed rank and t-tests P$\leq$.015). Likewise, they are lower than reported lumbar vertebral body and disc injury values. (4500 N to 8000 N; 5300 N to 11000 N[5]) with the exception of 2224 N that can occur in bent positions in highly degenerated or previously torn (bulging) lumbar discs.

	Thoracic Grades 0-1	**Thoracic Grades 2-3**	**Cervical [3]**	**Cervical [4]**
Injury Force	2976 N +/-118	2151 N +/-53	1909 N +/- 396	1900 N +/- 700

Table 1 - Mean Injury forces thoracic vs. cervical spine.

Injuries at 30.5 J primarily included cartilage and disc disruption (more annular than nuclear). 14% had endplate fractures. At 44 J damage to the spine segments with normal disc and bone (grade 1 disc degeneration and normal BMD) is limited to disc and cartilaginous disruption. 80% of the osteopenic samples had fractured endplates at 44 J.

CONCLUSION

At lower impact energy levels, disruption to the thoracic spine was mainly soft tissue. At more severe impacts, there is a higher likelihood of bony compromise to the spine. Furthermore, decreased bone mass predisposes individuals to a greater extent of bony disruption.

ACKNOWLEDGMENTS

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