Analysis of Mechanical Behavior of the Lumbar Spine Under High Impact Loading

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INTRODUCTION:

In the U.S. Naval environment, high speed boat (HSB) crewman often suffer from lower back pain and intervertebral disc (IVD) degeneration, due to the high G impacts experienced while navigating through open seas. In a self-reported study of injuries of HSB operators, 33.6% of these subjects had suffered a lower back injury[1]. The relationship between these high impact loads and disc biomechanics is not well understood. In this study, we analyze the changes in mechanical behavior, particularly compressive stiffness, of anterior column units (ACU) of the lumbar spine as a function of duration of impact. Understanding the mechanical behavior of the IVD during high impact loads, similar to those experienced by the high speed craft operators and crewman, may lead to an understanding of the degenerative process of the disc in this unique operational scenario.

METHODS:

Fresh frozen lumbar spine sections from four donors (mean age: 63 ± 8.8 years, range: 51-70 years), were used in this study, for a total of n=5 ACUs. The discs were thawed, dissected, and potted in Smooth Cast 300 (Smooth-On, Inc, Easton, PA). Anatomical measurements were taken (major and minor diameter, disc height) and the discs were graded to assess the gross morphology[2] (Table 1). The potted ACUs were fit into a custom-made jig[3] in a biaxial servohydraulic dynamic testing system (Model 8874, Instron Corp., Norwood, MA). A preconditioning sequence was run on each disc, in order to restore normal disc mechanics (50 cycles at 1Hz, -50N to -150 N compressive load). The discs were then put under a quasi-static loading sequence (sinusoidal waveform, 0.05, 0.10 and 0.50 Hz, +150N to -1KN) for 5 cycles each. From this data, we obtained load-displacement curves, demonstrating the typical viscoelastic response of IVD tissues. From these we determined the neutral zone of each disc.

ACU ID	Disc Level	Grade	Neutral Zone (mm)
1	L1-L2	5	0.148
2	L1-L2	2	0.200
3	L4-L5	3	0.127
4	L2-L3	3	0.457
5	L4-L5	3	0.157

Table 1: Disc level, degenerative grade, and neutral zone measurement for n=5 samples.

Each disc then underwent an impact loading sequence, similar to that experienced by HSB crewman, while under a 200N compressive preload. Each sequence consisted of six impact loads, with varying duration of load-recovery (10, 20, 40, 80, 160, and 320 ms). The discs were all compressed an amount equal to their neutral zone (see Figure 1). Maximum values for force, acceleration, and stiffness were calculated for each loading sequence using code developed with MATLAB software (The Mathworks, Natick, MA).

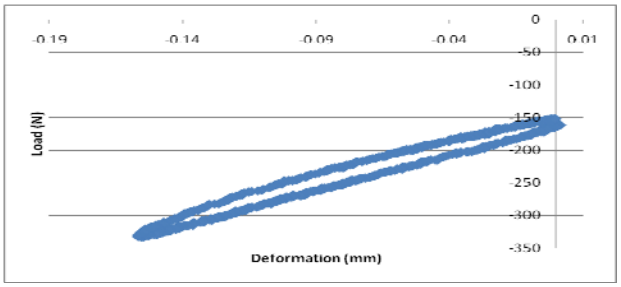

Figure 1: Load-deformation curve for ACU #5 under the 160ms impact load. Demonstrates a marked difference in behavior from normal viscoelastic tissues under quasi-static loading conditions.

RESULTS:

Figure 2 shows the load imposed on each ACU during impact testing. With the exception of ACU #1, there is a general trend of increasing force with increased impulse duration.

Figure 3 depicts the relationship between stiffness and impulse duration. All discs show a general trend of increased stiffness with reduced impact duration.

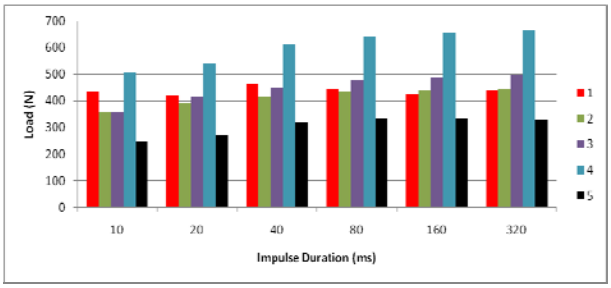

Figure 2: Compressive Load (+ sense) vs. Impulse Duration. Shows increasing force with increased time of impact loading.

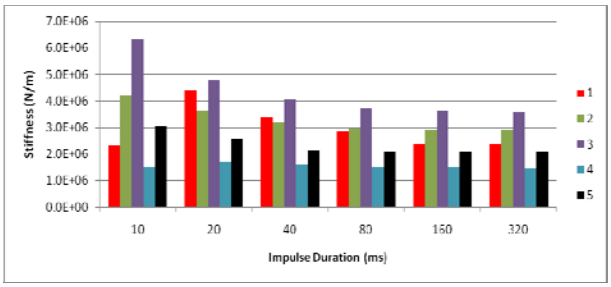

Figure 3: Stiffness vs. Impulse Duration. Shows increasing stiffness with reduced time of impact loading.

DISCUSSION:

The purpose of this study was to analyze the compressive mechanical behavior of the lumbar spine under high-strain-rate impact loads. The data shows that the IVD is more stiff under high impact loading conditions than under quasi-static conditions. The quasi-static compressive stiffness values for intact human motion segments reported in literature vary widely in a range of 700-3200 N/mm,[4] and the values reported for the high-impact loading in this study are generally above that range, particularly for the shorter impact loads. This shows that the highly demanding environment of naval HSB crewman is taxing on the IVD, and may provide insight into the high incidence of back pain and accelerated disc degeneration for this population.

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