INTRODUCTION

There have been numerous researchers that have investigated the properties of human intervertebral discs. However, there has been no attempt to characterize the effects of loading rate on the stiffness of human intervertebral discs. The purpose of this study was to develop the compressive stiffness properties of individual lumbar intervertebral discs when subjected to various dynamic compressive loading rates.

A total of 44 axial compression tests were performed on 11 individual human lumbar spine intervertebral discs dissected from 6 fresh frozen human cadavers, 5 male and 1 female. Functional spinal units (FSU), defined an intervertebral disc and the two adjacent vertebral bodies, were dissected from the cadavers. The FSU was fixed to a load cell with a custom aluminum pot and then subjected to dynamic compressive loading using a servo-hydraulic Material Testing System (MTS 810, 22 kN, Eden Prairie, MN).

METHODS

Prior to specimen preparation, lateral view digital radiographs were taken of each spine in order to identify any pre-existing degenerative changes. The intervertebral discs for each spine were graded, by a certified physician, on a scale of 1 to 4 based on criteria presented by Gordon et al. (1991). Intervertebral levels with a degenerative grade of 3 or 4 were rejected. A number of detailed steps were taken in order to ensure the spines were rigidly secured while maintaining the proper testing orientation. After the spine was sectioned into the desired FSU, all the soft tissue except the ligaments was removed from the FSU. Second, a custom potting cup was filled with a bonding compound (Bondo Corporation, Atlanta, GA), and one half of the proximal vertebral body of the FSU was placed into the bonding compound. Special care was taken to ensure that the mid-plane of the disc was parallel with the potting cup, and that the disc was centered in the potting cup. This potting orientation has been used by numerous previous authors (Yoganandan et al., 1989; Lin et al., 1978; Gordon et al., 1991; Brickmann et al., 1989). The potted vertebrae was then attached to the MTS actuator, and the distal potting cup was filled with the bonding compound. Finally, one half of the distal vertebral body was lowered into the distal potting cup. This procedure prevented any induced flexion or extension moments.

Each intervertebral disc was subjected to a four part test battery in which the loading rate was increased with each test. First, the intervertebral disc was preconditioned to a displacement of 0.5 mm at a rate of 1 Hz, which is similar to the frequency of normal walking. Each intervertebral disc was then subjected to two dynamic displacement steps, 0.5 mm and 1.0 mm, at rates of 0.1 m/s and 0.2 m/s respectively. Finally, each intervertebral disc was subjected to a
dynamic failure test at a rate of 1.0 m/s. However, due to the length limitations the failure results are not presented in this paper. After each test, the MTS actuator was returned to the original position of zero strain and the specimen was allowed to relax for 10 minutes. The specimen was kept hydrated during the entire preparation and testing process by spraying saline directly on the specimen.

Points used to calculate stiffness and strain rate values were taken at approximately 25% and 50% of the loading curves. Strain was calculated based on the lateral disc height obtained from the digital X-rays.

RESULTS AND DISCUSSION

The loading rate for preconditioning, 0.0001 m/s, resulted in an average stiffness and strain rate of 375.8 ± 55.8 N/mm and 0.01 ± 0.0 s⁻¹. The loading rate for the first step test, 0.1 m/s, resulted in an average stiffness and strain rate of 1835.1 ± 645.6 N/mm and 6.8 ± 1.5 s⁻¹. The loading rate for the second step test, 0.2 m/s, resulted in an average stiffness and strain rate of 2489.5 ± 474.1 N/mm and 13.5 ± 2.0 s⁻¹. The loading rate for the failure tests, 1.0 m/s, resulted in an average stiffness and strain rate of 6551.1 ± 2017.0 N/mm and 72.7 ± 16.8 s⁻¹.

The results show that the stiffness of lumbar intervertebral discs is highly dependent on the loading rate. Carter (1977) reported that ultimate compressive strength and modulus of human compact and trabecular bone are proportional to the strain rate raised to 0.06 power. Therefore, a relationship similar to the one developed by Carter (1977) was developed. The resulting relationship shows that the stiffness of lumbar intervertebral discs is proportional to the strain rate raised to the 0.29 power (Figure 1).

\[ y = 1311x^{0.29} \]

\[ R^2 = 0.88 \]

\[ \text{Figure 1: Relationship of intervertebral disc stiffness to strain rate.} \]

Note: log-log scale.

SUMMARY/CONCLUSIONS

The compressive stiffness properties for the individual lumber intervertebral discs were determined at various loading rates. The results show that the stiffness of lumbar intervertebral discs is highly dependent on the loading rate. It was determined that the stiffness of lumbar intervertebral discs is proportional to the strain rate raised to the 0.29 power.

REFERENCES


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