HIGH-RATE VISCOELASTIC PROPERTIES OF HUMAN CERVICAL SPINAL INTERVERTEBRAL DISCS

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INTRODUCTION

The neck is vulnerable to injury in automotive and military crash scenarios. To investigate these injuries and develop countermeasures, computational models of neck response may be used. In these models, it is imperative to have accurate material properties of the internal soft tissues derived using appropriate loading rates. The purpose of this study was to determine high-rate viscoelastic properties of human cervical spinal intervertebral discs. The viscoelastic model, derived from human experimental data, was compared based on location on the anulus and gender.

METHODS

Ten human cadaver cervical spines (5M, 5F) were used in this study. The average male age, stature, and mass were 60.2 ± 10.3 yr, 1821 ± 44 mm, and 99.2 ± 12.2 kg. The average female age, stature, and mass were 43.7 ± 17.8 yr, 1687 ± 85 mm, and 75.4 ± 28.1 kg. The cervical discs were isolated from each cervical spine at C3-C4, C5-C6, and C7-T1 and localized indentation tests were performed on four sites on the anulus fibrosus (Figure 1). The inferior vertebral body remained for each disc. A total of 93 cervical intervertebral discs were tested. A 2.75 mm diameter spherical head indenter was used for all tests.

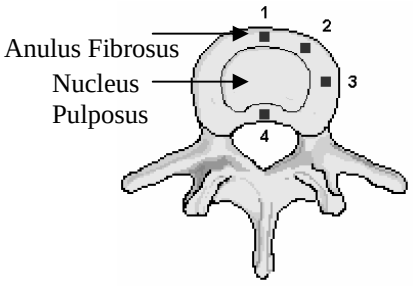

Figure 1. Schematic of intervertebral disc. Indentation tests were performed on the sites marked 1-4.

A series of incrementally increasing strain ramp-hold inputs were applied to each spot. The tests were performed in an environmental chamber at appropriately physiological conditions (~99 °F, ~100% RH). An analytic solution of average true strain and average local true stress was developed. A viscoelastic material model was determined from the nonfailure tests using quasi-linear viscoelasticity theory (c.f. Lucas *et al.*, 2004). The relaxation function in the QLV model was comprised of four relaxation coefficients, with corresponding time constants, and a steady state coefficient (Table 1). The model was developed using the average true strain and average local true stress beneath the indenter.

Table 1. Summary of G_n and corresponding time constants.

G_n	G_1	G_2	G_3	G_4	G_∞
Time Constant (ms)	1000	100	10	1	----

RESULTS AND DISCUSSION

The highest weighted relaxation coefficient, G_4, corresponds to a time constant of 1 ms. This indicates that at high-rates, the intervertebral disc relaxes early in the strain ramp onset. The next highest weighted coefficient, G_∞, is the steady state coefficient. Comparisons were made between annulus site and gender. Figure 2 is a comparison of G_4 and G_∞ based on annulus site. There is no substantial difference in G_4 or G_∞ between site 1 and site 4. G_4 is slightly higher in site 2 and site 3, which are located on the anterior-lateral and lateral aspects of the anulus, respectively.

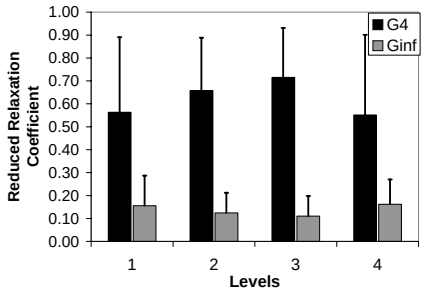

Figure 2. Comparison of relaxation coefficients based on anulus site

Figure 3 is a comparison of G_4 and G_∞ based on gender. The male G_4 is larger than the female G_4, indicating that more relaxation is occurring in the ramp onset for the male discs. Consequently, the female G_∞ coefficient is larger than the male G_∞ coefficient, since the sum of the relaxation coefficients is one. Differences in male and female relaxation coefficients may be attributed to the amount of disc degeneration. Males have a higher prevalence of disc degeneration. Additionally, the average age of male subjects in this study was larger than the average age of the female subjects. Disc degeneration is certainly exacerbated with age.

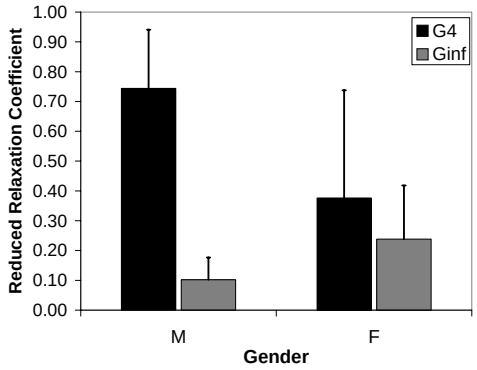

Figure 3. Comparison of relaxation coefficients based on gender. Anulus sites 1-4 are grouped together in this comparison.

SUMMARY/CONCLUSIONS

The primary objective of this study was to investigate high-rate viscoelastic properties of cervical spine intervertebral discs. It has been shown that there is a large amount of relaxation early in the strain ramp onset. There are no substantial trends in the relaxation coefficients based on anulus site; however, there are discernable differences in relaxation based on gender.

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