STIFFNESS AND ENERGY DENSITY VARIATION WITH RESPECT TO FREQUENCY IN A THORACOLUMBAR SPINE DURING CYCLIC LOADING

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INTRODUCTION

Back injuries were the most common non-fatal occupational injuries according to data reported by the Bureau of Labor Statistics between 1980 and 1997 [1], with no substantial changes observed up to 2003 [2]. Compressive forces acting on the thoraclumbar spine during repetitive moderate to heavy lifting tasks were found to be a significant factor leading to fatigue fractures, and hence injuries, of the lower back [3]. Although lifting limits and guidelines derived from prior studies were implemented, between 1997 to 2007 direct costs associated with back injuries increased from $12.2 to $90.0 billion in the United States alone [4].

Prior studies analyzed the effect of loading using damage measures such as cycles to failure and accumulated strain, but typically used high loading rates (frequencies) and loads, not representative of typical work conditions. The present study examines the effects of cyclic loading using stiffness changes and energy dissipated per unit volume, energy density (ED), at two typical loading frequencies of 6 and 12 lifts per minute (0.1 and 0.2 Hz).

METHODS

38 fresh thoracolumbar spine motion segments were dissected from 12 human cadavers ranging in age from 53 to 91 years. Motion segments were positioned at their natural standing position curvature Harrison angles utilizing a specially designed loading fixture. A compressive preload of 350 N was applied for 15 minutes to reduce postmortem effects and simulate torso load. 18 segments were monotonically tested to compressive failure at a rate of 4mm/hr, with a drop in sustained force indicating failure. Two randomized groups of 10 segments each were tested at loading frequencies of 0.1 and 0.2 Hz for a period of 8 hours. The loading magnitude was set at 50% of failure stress measured from the monotonic testing of a segment from the same spine.

RESULTS AND DISCUSSION

Average stiffness was calculated for multiple cycles throughout the loading history. The stiffness at 0.2 Hz loading was higher than at 0.1 Hz loading at every cycle. During the initial cycles, the difference in stiffness was 37% with the difference decreasing to 20% by the 300th cycle. Average stiffness increased at a continuously decreasing rate throughout the loading period. ED, on the other hand, exhibited a steady increase over the entire 8-hour loading period. The energy density per cycle was virtually identical for both loading frequencies, varying by less than 10% for all cycles. The energy density dissipation per cycle decreased with loading cycles, approaching 65% of the initial value at the end of the testing.

The viscoelastic intervertebral disc becomes stiffer and its ability to dissipate energy decreases with cycling. Both phenomena are likely due to loss of water from the disc and the subsequent reduction in viscous behavior. As the stiffness increases, the chances of fatigue failure also increases [5] due to higher resistance provided by the disc to the applied cyclic compressive loading. Increased stiffness in the disc results in greater deformation demand being placed on the endplates, which are the most susceptible element of the spinal motion segment. Segment strain and stiffness exhibited saturation with cycling. That is, the rate of change of both strain and stiffness slowed considerably after a number of cycles. On the other hand, ED was not subject to saturation (Figure 1).

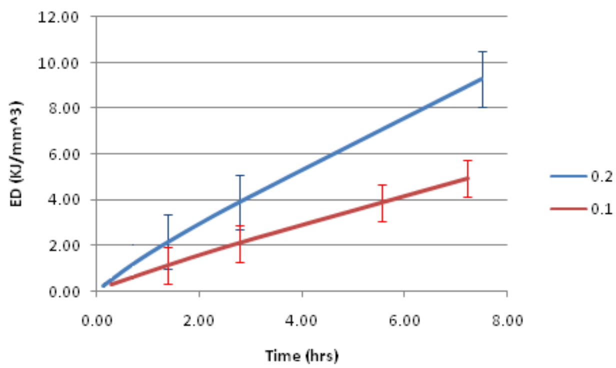

Figure 1: Average ED of all motion segments tested at 0.1 and 0.2Hz over an 8-hour period.

CONCLUSIONS

Segment stiffness is highly dependent on the loading frequency due to the viscoelastic nature of the disc. However, ED *per cycle* was found to be relatively independent from loading frequency and did not exhibit saturation. Further research is required to quantify the effect of frequency on damage measures such as ED to provide insight into behavior of intervertebral discs subject to repetitive loading.

REFERENCES

1. Mital A., et al. Nonfatal occupational injuries in the US Part II- back injuries. *INT J IND ERGON* **25**:131-50,1999.
2. CDC. Nonfatal occupational injuries and illness treated in hospital emergency departments – US, 1998, MMWR **50**:313-7, 2001.
3. Lotz JC., et al. Intervertebral disc cell death is dependent on the magnitude and duration of spinal loading. *Spine* **25**:1477, 2000.
4. Dagenais S., et al. A systematic review of low back pain cost of illness studies in the United States and internationally. *The Spine Journal* **8**:8-20, 2008.
5. Hansson TH., et al. Mechanical behavior of the human lumar spine. II: Fatigue strength during dynamic compressive loading. *Journal of Orthopaedic Research* **5**:479-87, 1987.