Non-Destructive Materials Testing Techniques Used to Assess the Degradation of Intervertebral Discs Subjected to Pseudo-Physiologic Repetitive Loads

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Introduction

Low back problems present a significant burden on society. Studies indicate that between 5% and 9% of the general U.S. population seeks professional health care annually at a cost in excess of $30 billion (Waddell, 1996). In the United Kingdom, the percentage increases to 8 – 13%, at an annual cost of $1 billion. Several mechanical loading conditions have been cited as risk factors associated with low back problems. Specifically, epidemiological and morphological studies have shown that repetitive lifting increases the incidence of disc degeneration, disc herniation, and low back pain (Magora et al. 1972, Kelsey et al. 1975, Frymoyer et al. 1983, Videman et al. 1990). More recently, in vitro experiments have shown an intensification of stresses in the posterior disc resulting from pseudo-physiologic, non-traumatic flexion loading (Adams et al. 1994, Hedman and Fernie 1997). Also of interest, Osti, et al., (1992) studied 135 cadaveric specimens and found a close relationship between radiating tears of the posterior annulus and severe nuclear degeneration. Together, these studies suggest a cause and effect relationship between normal repetitive loading and degeneration of the posterior disc and ligament. This relationship has not been demonstrated experimentally or quantified.

Using standard tensile testing techniques, the authors have previously demonstrated a link between degradation of elastic-plastic material properties and repetitive loading of the posterior disc and ligament. Statistically significant drops in yield strength and energy absorbed prior to yield, and a marginally significant drop in ultimate stress were found in post-fatigue (2000 cycles, maximum load 33% of control yield stress) specimens. It is reasonable to suggest that in an environment with limited biological response, repetitive sub-traumatic loading of intervertebral joints may contribute to degradation of the tissue, leading to an increased vulnerability to mechanical loading and, eventually, to spinal instability and pain. With regard to the disc’s ability to repair and regenerate tissue, it should be noted that the mature disc is a principally avascular structure relying on diffusion for nutrition of its limited number of viable cells. Age related changes interfere with diffusion, presumably contributing to declining cell viability and biosynthetic function. This age related decline in numbers of cells and cell functionality compromises the ability of the cells to repair mechanical damage to the matrix.

Non-destructive materials testing techniques provide means of determining elastic-plastic and viscoelastic material properties at multiple points along a prescribed time or loading history. Hardness, or resistance to penetration, is related to several fundamental material properties. Empirical relationships between hardness and ultimate tensile strength, elastic modulus, yield strength and fatigue strength have been determined in biological materials (Evans et al., 1951, Kawchuk, 1998). Similarly, stress relaxation methods have been commonly used to determine the viscoelastic nature of biomaterials (Dunn et al., 1983, Purslow et al., 1998).

Therefore, the aims of the present study were:

1) To develop a non-destructive means of determining material properties at several points along a well-defined repetitive loading history.
2) To isolate the material properties of the posterior annulus while applying pseudo-physiologic loads to the whole intervertebral joint.
3) To confirm deterioration of disc material properties due to non-traumatic cyclic loading.
Methods

Non-destructive indentation testing techniques were used to determine elastic-plastic and viscoelastic material properties at multiple points along a prescribed time or loading history. Disc hardness (related to displacement at 50 N maximum ramp load), static creep (60 second) and stress relaxation (60 second) measurements were made on the anterior, posterior, left and right lateral aspects of 12 calf lumbar intervertebral joints. These measurements were made after 10 cycles of pre-conditioning and, for 8 of the specimens, following each of three sets of 2000 combined compression-flexion loading cycles (magnitude: 200 N, 40 mm anterior to center of disc). The other 5 specimens were not loaded and served as controls. Non-destructive materials tests were conducted on the controls at time periods equal to those of the loaded specimens. The test apparatus included a 6.8 mm diameter spherical indenter attached to an MTS 858.02 servo-hydraulic test system. The specimens were kept wrapped in saline soaked gauze to maintain moisture throughout fatigue cycling. Spearman’s non-parametric correlation analysis and Friedman’s non-parametric rank analysis were used to analyze the correlations between material properties and numbers of loading cycles.

Results and Discussion

Consistent trends were found indicating moderate degradation of material properties of the posterior annulus corresponding with physiologic-cyclic loading. Stress relaxation increased by 23% on average and static creep increased by 18% (Fig. 1). The changes in hardness were considerably more variable with a general decline in hardness due to repetitive loading. No significant trends were found in any of the other regions of the disc or in any of the controls.

![Figure 1](image-url)  
*Figure 1:* Mean values of three materials properties expressed as a percentage of initial values (after pre-conditioning). Spearman’s correlation coefficient with associated probability is shown for each curve.

The non-destructive materials testing results indicate progressive degradation of the material properties of intervertebral discs due to repetitive sub-traumatic flexion loading. Repetitive sub-traumatic loading produced statistically significant changes in stress relaxation and creep in the posterior intervertebral discs of four-month old calf spines. An increase in stress relaxation and creep deformation in the posterior disc may signal a general loss of structural integrity and a general weakening of the tissue. These results are in agreement with the previously mentioned destructive tensile testing results that showed a significant reduction in yield strength and energy absorbed prior to yield associated with repetitive sub-failure loading of tensile specimens harvested from the region of the posterior disc (Fig. 2).
It is reasonable to suggest that in the presence of limited biological regeneration and healing, repetitive sub-traumatic loading of intervertebral joints may contribute to tissue deterioration, leading to spinal instability and pain. The non-destructive, in vitro techniques have been shown to be useful in quantifying the vulnerability of intervertebral tissues to fatigue.

These non-destructive techniques are now being used along with our tensile testing techniques to further quantify the relationship between mechanical loading and degradation of intervertebral joint tissues.

References


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