PARTIAL NUCLEOTOMY ALTERS THE FATIGUE-RECOVERY OF THE INTERVERTEBRAL DISC

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Introduction: Degeneration of the intervertebral disc is accelerated following herniation or partial discectomy. While the mechanisms for the initiation of this degeneration are not well understood, decreased proteoglycan content, mechanical fatigue loading, and other factors have been suggested [1]. Proteoglycans and their associated charged glycosaminoglycans maintain an osmotic pressure within the nucleus pulposus. A decreased proteoglycan content, therefore, will cause a pressure loss and alter the loading state throughout the disc. The acute effects of partial nucleotomy in vitro are unclear; some have shown an immediate decrease in compressive stiffness [2–4], while others have found no change [5,6]. The inconsistent findings among these studies may relate to the degenerative state of the disc and possible damage to the annulus fibrosus during treatment. In addition, the effect of partial nucleotomy on the fatigue-recovery of the disc has not been previously studied. The goal of this study, then, was to determine the mechanical effect of partial nucleotomy on the acute, fatigue, and most importantly, the fatigue-recovery compression behavior of non-degenerate discs. We hypothesized that with partial nucleotomy there would be a decrease in disc stiffness and a diminished ability to recover following fatigue loading.

Materials and Methods: Six lumbar spines were harvested from normal adult sheep using an IACUC approved protocol. Facet joints and transverse processes were removed and motion segments from the L3-L4 level were prepared by making two parallel axial cuts through adjacent vertebral bodies. Motion segments were potted in PMMA bone cement.

Motion segments were mechanically tested in an Instron 5543 test system. All tests were carried out in a PBS bath to maintain tissue hydration. After application of an initial 15 N tare load samples were subjected to 50 cycles between 15 and 400 N compression, a stress-relaxation test, and a slow 1 N/s ramp to 400 N compression. Following this protocol, samples were subjected to 10,000 cycles of compression between 15 and 400 N at 1 Hz then placed in a PBS bath and refrigerated for 18 hours to allow recovery and re-hydration. In the treatment group (n=3) a 4 mm diameter plug was drilled parallel to the long axis of the spine, through the vertebral body and endplate, and through the center of the nucleus pulposus. Importantly, this left the annulus fibrosus intact. The disc remained unaltered in the control group (n=3). Acute mechanical behavior was then assessed within a loading protocol described above. A second set of 10,000 compression cycles was applied and the post-fatigue mechanical behavior measured. An additional 18-hour re-hydration recovery period was followed by a final measure of the mechanical properties.

Elastic stiffness was calculated using a linear regression of the force-displacement curve between 100 and 400 N. Differences between the control and treatment groups were evaluated using unpaired t-tests; differences within the treatment group were evaluated using paired t-tests. Significance was set at p<0.05.

All samples were radiographed immediately prior to and after testing. Following the test protocol, changes in disc microstructure and fluid content were assessed using proton density-weighted magnetic resonance imaging in a representative sample from each group.

Results: Depressurization treatment resulted in an immediate 33% decrease in elastic stiffness when compared to the intact group (Fig 1-Acute). Fatigue loading produced similar effects for both intact and treatment groups; the mean stiffness increased by 22% and 38%, respectively (Fig 1-Post Fatigue). After the recovery period, stiffness in the intact group returned to normal, whereas stiffness in the treatment group remained elevated (Fig 1-Final).

Radiographs taken before and after treatment showed no signs of failure within the endplates or vertebral bodies in either group. In addition, the radiographs showed:

- Increased vascularization
- Radiopaque material within the disc

Discussion: The most significant finding in this study was that the compressive stiffness of discs subjected to partial nucleotomy did not recover from cyclic loading. There were also observed losses in disc height and water content. Such changes are consistent with those observed clinically in degenerated discs and following partial discectomy. These findings suggest, therefore, that inability to recover from cyclic loading may be an important mechanism in the accelerated degeneration known to occur in herniated discs. While the effects of nucleotomy and/or cyclic loading have been studied previously [2–9] this is the first study to examine the effect of nucleotomy on fatigue recovery.

The inability to recover may be explained by a decreased osmotic pressure within the disc. Approximately 40% of the nucleus pulposus was removed during the initial partial nucleotomy treatment. The associated removal of proteoglycan and glycosaminoglycan resulted in a decreased charge density within the nucleus pulposus. There was therefore a lower mechano-electrical gradient for water resorption in the unloaded state. It is possible that a similar inability to recover occurs in vivo with nucleotomy and with age-related loss of proteoglycan and glycosaminoglycan.

A strength of this study was our technique of performing partial nucleotomy through the endplate, leaving the annulus intact. This ensured that our findings were related to the nucleus pulposus treatment and not to acute damage to the annulus fibrosus. Our findings for an immediate decrease were different from a related study in which a total denucleation through the endplate did not change the acute compressive stiffness [6]. Some denucleation studies have reported an acute decrease in axial compressive stiffness, consistent with our findings [2–4], while others have not [5,6]. The acute decreased stiffness is likely due to reduced radial bulge and decreased circumferential hoop stress in the annulus fibrosus that occur under decreased nucleus pulposus pressure [8–10].

In conclusion, the effect of partial nucleotomy was a diminished capacity to recover from cyclic loading. This has clinical significance in understanding mechanisms of degeneration. Perhaps the diurnal loading-recovery cycle is impaired in early degeneration or following herniation. Loss of recovery, then, may be a critical mechanism in the progression of disc degeneration.


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