Recovery of Human Intervertebral Disc Motion Segments Following Axial Compression Loading

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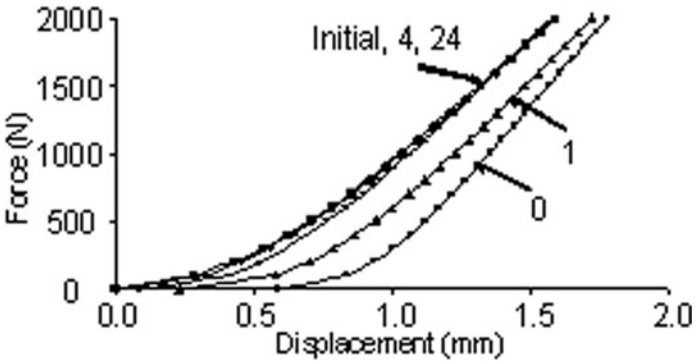
Introduction: The hydrated intervertebral disc functions to absorb energy, permit motion, and transfer spinal loads. Fluid flow determines the time-dependent viscoelastic mechanics of the disc and is critical for investigations regarding disc function, degeneration, diurnal loading, and nutrition. Furthermore, recovery following loading is important for repeated loading in cadaveric motion segment studies. Due to the internal pressure, application of an external load drives fluid out of the disc. Re-equilibration via unloaded recovery, where passive diffusion restores the osmotic imbalance, takes much longer [1-3]. If the disc is not permitted to fully recover, the original disc height and mechanical behavior is altered, including increased stiffness [2, 4]. There are conflicting data regarding recovery time following compressive loading, with times ranging from 40 min to 18 hours, which are dependent on loading protocols and species studied [2, 3, 5-7]. The objective of this study was to determine the time for unloaded recovery of disc height and stiffness following compressive loading in a human motion segment.

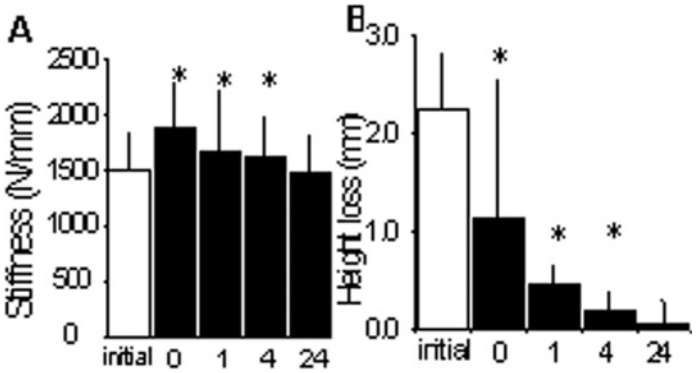
Materials and Methods: Motion segments were prepared from level L1-L2 and/or L2-L3 from six human spines (n = 8; 22 - 77 years old, grades 1- 4). A bone-disc-bone motion segment, with posterior facets removed, was potted in bone cement, then wrapped in gauze and hydrated in a refrigerated PBS bath for 15 hours. The sample was equilibrated for three hours at room temperature before testing and was kept wrapped in saline-soaked gauze during testing. Each sample was tested with a ramp compression to 2000 N at a rate of 1 N/s (loading time of 33 min). Repeat testing following four recovery times, 0, 1, 4 and 24 hours, was performed for each sample in random order, with unloaded recovery in a PBS bath. Stiffness was calculated as the slope of the linear region of the force-displacement curve. Disc height loss was calculated as the change in initial position of the Instron crosshead at 0 N load. A paired t-test was used to compare stiffness and height loss to initial values.

Results: The force-displacement response was nonlinear (Fig 1), the 0 and 1 hour recovery group were clearly different from the initial. The 4 and 24 hour recovery were largely indistinguishable from the initial response, except for early in the 4 hour response. Note that the initial position at zero load includes the loss in disc height. The initial stiffness was 1487 N/mm and the height loss (displacement) at 2000 N load was 2.26 mm, approximately 25% of initial disc height (average height of 9.1 mm, Fig 2). The 0 hour recovery group experienced a 27% increase in stiffness ($p < 0.05$, Fig 2A) and a 1.1 mm loss in disc height ($p = 0.06$, Fig 2B). For the 1 and 4 hour recovery time points, the stiffness increased by 12% and 9%, respectively ($p < 0.05$, Fig 2A). The average disc height loss was 0.45 mm and 0.19 mm for 1 and 4 hour recovery, respectively ($p < 0.05$, Fig 2B). No significant difference was found in either the stiffness or the disc height following 24 hours recovery (Fig 2).

Discussion: This study demonstrated that the intervertebral disc recovers initial stiffness and disc height within 24 hours following a compressive load to 2000N applied over 33 min. This is a conservative estimate, as the loading applied (2000N over 33 minutes, ~2.4X body weight) and the displacements achieved (2.3 mm, compared to 1.5 mm height loss over 6 hrs creep at 1000N and with 1.5 mm diurnal disc height loss in vivo [8]) were relatively high. Full recovery may have occurred between 4 and 24 hours. A recovery time of approximately 8 hours would be comparable to the diurnal recovery of the disc; future studies will add intermediate time points. Recovery time, which will depend on loading history, has been reported to range from 40 min to 18 hours [2, 3, 5-7]. Riches et al demonstrated a short recovery time of 40 min after applying a 20 min creep load [7], which is inconsistent with the present study. MacLean et al also found 6 hours of recovery to be insufficient to recover from 4 hours of loading in the rat caudal disc [5]. Longer recovery times, comparable with this study have been reported for ovine and porcine discs [3, 6]. Several factors may influence recovery and may account for the conflicting data in the literature, including varied loading protocols (such as ramp or creep, max load), the amount of time the load is applied, the size of the disc, and the disc's degenerative state. Mathematical models that accurately describe fluid outflow and inflow are needed to extrapolate the recovery times determined here for a specific loading condition to any general loading history.



Response curve for a representative sample



A) Initial stiffness (white) and recovery groups 0, 1, 4 and 24 hours (black). B) Initial height loss (white) defined as the displacement at 2000 N and the height loss after recovery (black) as the height at 0 N.

In conclusion, this study demonstrated full recovery from 2.3 mm axial displacement applied under 2000 N load over 33 minutes within 24 hours. Full recovery likely occurred between 4 and 24 hours, as the force-displacement curves were similar.

References: [1] Ayotte et al, JOR 1073-77, 2001; [2] Costi et al, Clin Biomech. 446-55, 2002; [3] Johannessen et al, Ann Biomed Eng, E724-9, 2004; [4] Race et al, Spine 662-9, 2000; [5] MacLean et al, J Biomech 55-63, 2007; [6] Van der Veen et al, Spine E534-9, 2006; [7] Riches et al, J Biomech 1263-71, 2002; [8] Adams Spine 130-7, 1987