RECOVERY OF HUMAN DISC HEIGHT ANS STIFFNESS FOLLOWING AXIAL COMPRESSION

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Introduction: Hydration strongly influences disc mechanics and fluid flow determines time-dependent viscoelastic behaviors. Hydration and flow are continually re-balancing under externally applied load and internal osmotic pressure. There still remain open questions regarding the time course and pathways for fluid motion [1]. Furthermore, it is unknown whether in vivo diurnal recovery, where a steady state recovery of disc height occurs for 8 hours of rest following 16 hours of loading, can be achieved in vitro [2-3], where recovery times twice as long as loading times do not achieve full restoration of disc height or stiffness. Answers to these questions are critical for investigations regarding disc function, degeneration, diurnal loading and nutrition. In addition, establishing full recovery following loading is important for in vitro experiments with repeated loading. Although unloaded recovery times have ranged from 40 min to 18 hours and have achieved various degrees of restoration [4-8], to our knowledge, no study has systematically determined how much unloaded recovery time is needed following physiologically relevant axial compression. 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: Eight L1-L2 and/or L2-L3 bone-disc-bone motion segments with posterior facets removed were prepared from six human spines (22 - 77 years old, grades 1- 4). Each segment was potted in bone cement, 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 quasi-static rate of 1 N/s (loading time of 33 min). Repeat testing was performed, in random order, following unloaded recovery in a PBS bath for times of 0, 1, 4, 8, 12, 16 and 24 hours. Stiffness was calculated as the slope of the linear region of the force-displacement curve. Disc height loss was calculated as the change in position of the loading platen at 0 N load. A paired t-test was used to compare stiffness and height loss to initial values.

Results: The force-displacement response, shown with the initial 0 N position including the disc height loss, was nonlinear (Fig 1). The 0 and 1 hour recovery groups were shifted to the right, compared to the initial condition due to the loss in disc height. The remaining recovery groups tended toward the initial condition curve, with the longer recovery times being closest to the initial force-displacement response (Fig 1). The initial stiffness was 1548 ± 342 N/mm with a displacement of 2.02 ± 0.41 mm at 2000 N. This represents approximately 22% of the disc height (average height 9.1 mm). The 0 and 1 hour recovery groups were stiffer than the initial condition by 18 and 24%, respectively ($p < 0.001$, Fig 2A). The 0, 1 and 4 hour recovery groups had a loss in disc height of 1.1, 0.5 and 0.2 mm, respectively ($p < 0.02$, Fig 2B). No significant difference in stiffness was observed for the 4 hour recovery group ($p = 0.2$); no significant differences were found in either the stiffness or the disc height following recovery times of 8 hours or longer (Fig 2). The 8, 12, 16 and 24 hour recovery groups had a change in stiffness of less than 2% and change in initial height less than ± 0.1 mm or 1%.

Discussion: This study demonstrated that the intervertebral disc recovers initial stiffness and disc height following a ramp compressive load to 2000 N and 2 mm displacement (>20% axial strain) applied over 33 min within 8 hours of unloaded recovery. In vivo, the disc recovers to a diurnal steady state value with overnight 'unloaded' rest following physiological loading that produces approximately 1.5 mm height loss [9]. Even though the loading time was much less than the duration of daily loading, it is likely that the height loss observed in vivo occurs relatively quickly under standing loads, after which equilibrium between external load and internal pressure is achieved. Therefore, the high load and 2 mm displacement over 33 min in this study, that exceeds normal diurnal height loss, is a reasonable approximation of diurnal loading cycle. In that case, this study supports the notion that in vitro recovery time of eight hours is representative of in vivo diurnal disc recovery. It is likely that the mechanisms for hydration and fluid flow observed in vivo and in vitro are similar, as they are driven by physical, chemical and mechanical processes rather than biological ones. Thus, previous and future experiments to elucidate diffusion pathways, fluid flow, permeability, and time constants remain valid and will provide key information toward understanding the mechanisms of degeneration and disc nutrition.

Recovery of the disc is dependent on the loading magnitude and duration. Recovery times from less than 1 hour up to 18 hours have been used to restore the disc's properties [4-8]; however, they have not always achieved restoration of disc height or mechanics. 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 size of the disc, and the disc's degenerative state. Mathematical models that describe fluid outflow and inflow are needed to extrapolate the recovery times determined here for a specific loading condition to any general loading history. Based on the ramp protocol used in this study, which included both nondegenerate and degenerate human discs, 8 hours unloaded recovery is sufficient for recovery from a 2 mm disc height loss.

References: [1] Ayotte et al, JOR 1073-7, 2001; [2] Adams et al, Spine 130-7, 1987; [3] Tyrell et al, Spine 161-4, 1985; [4] Costi et al, Clin Biomech. 446-55, 2002; [5] Johannessen et al, Ann Biomed Eng, E724-9, 2004; [6] MacLean et al, J Biomech 55-63, 2007; [7] Van der Veen et al, J Biomech 2230-5, 2007; [8] Riches et al, J Biomech 1263-71, 2002; [9] Adams Spine 130-7, 1987

Acknowledgements: This study was supported by NIBIB and NIAMS.

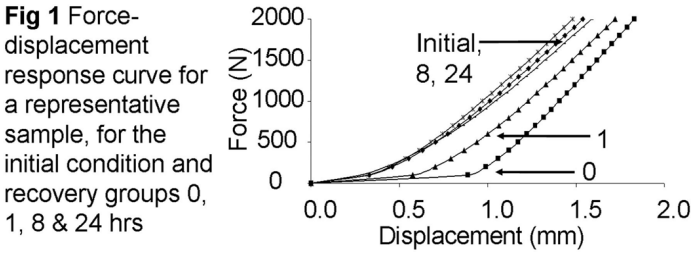

Fig 1 Force-displacement response curve for a representative sample, for the initial condition and recovery groups 0, 1, 8 & 24 hrs

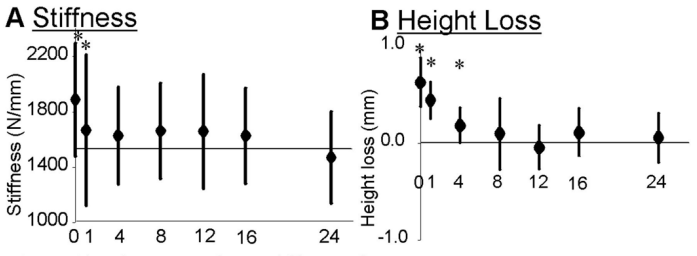

Fig 2 A) Linear region stiffness for recovery groups 0, 1, 4, 8, 12, 16 and 24 hours. B) Height loss after recovery. * denotes significance from initial condition.