Osmotic Loading Environment Alters Intervertebral Disc Mechanical Function

Semih E. Bezci, Joseph M. Felipe, Grace D. O'Connell*
Department of Mechanical Engineering
University of California, Berkeley

Diurnal loading causes changes in intradiscal water content and volume, altering the osmotic environment. Osmotic loading has been shown to alter cellular metabolism and tissue mechanics; however, it is not clear how these sub-level changes affect disc joint mechanical function. The aim of this study was to evaluate the effect of osmotic loading on viscoelastic function of a healthy intervertebral disc.

Skeletally mature (16-18 months) bovine caudal spine sections were acquired from the local abattoir. Bone-disc-bone motion segments were prepared and the boney ends were potted in bone cement to ensure flat parallel surfaces for mechanical testing (n=5). Samples were hydrated in 1X or 20X saline solution (0.1 or 2.0M, respectively). Creep behavior was analyzed by applying a 1000N for 2.5 hours. Data was fit to a rheological model to determine equilibrium modulus. Samples were allowed to recover, then, a slow-loading rate ramp was performed. The toe- and linear-region stiffness was calculated. A paired t-test was performed with significance assumed at $p \leq 0.05$.

The equilibrium modulus was 4.7±2.1MPa for samples hydrated in the 1X solution and decreased to 3.6±1.8MPa for the 20X group (p=0.05; model-fit $R^2>0.98$; Fig. A). The linear-region stiffness calculated during the creep load was applied (15s ramp) of the 1X condition was 40% greater than the 20X condition (p=0.02; Fig. B). As expected, there were no significant differences in the elastic mechanical tissue behavior, which was measured during the slow-loading rate ramp (pooled toe-region stiffness = 316±60N/mm, linear-region stiffness = 851±61N/mm; p>0.3; Fig. B).

Osmotic loading was used to mimic the environment experienced during diurnal loading. The nucleus pulposus is a highly viscoelastic material, due to its glycosaminoglycan content. However, the equilibrium modulus in the 1X condition was only 30% greater than the 20X condition, which is much lower than the 5-fold difference observed in cartilage.[1] These differences in compression mechanics are likely due to the more elastic behavior of the annulus fibrosus and load transfer to the annulus at physiological loads. The significant increase in displacement for a less hydrated disc (20X group) may have significant implications for radial bulging and recovery, which will be investigated next.

Reference:

Chahine NO, Wang CCB, Hung CT, and Ateshian GA. Anisotropic strain-dependent material properties of bovine articular cartilage in the transistional range from tension to compression. J Biomech 37:1251-61, 2004.

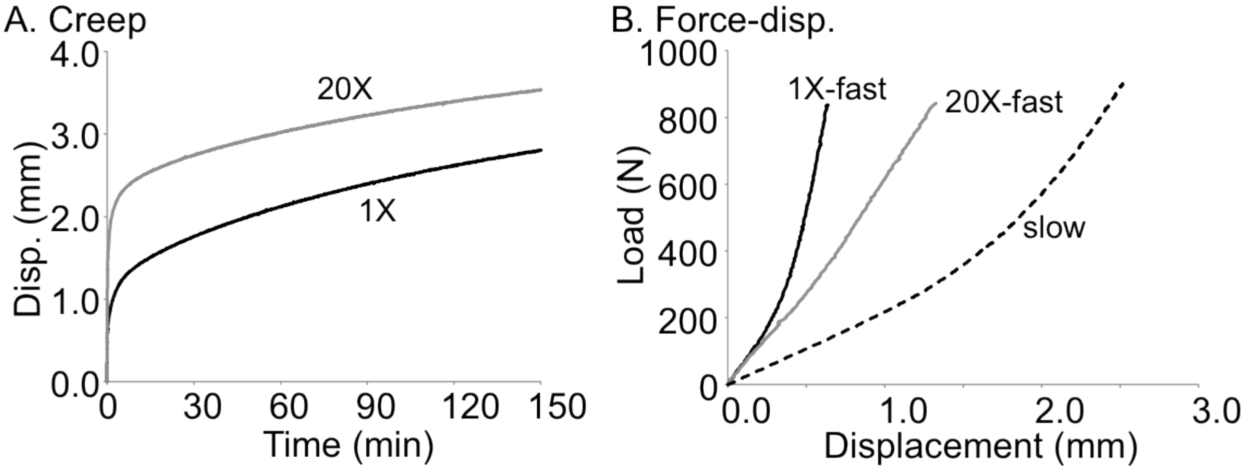

Figure. A) Creep displacement and (B) force-displacement behavior of a representative sample. Slow-loading rate response was not significantly different between the 1X and 20X group.