Research paper

Axial creep loading and unloaded recovery of the human intervertebral disc and the effect of degeneration

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\begin{abstract}
The intervertebral disc maintains a balance between externally applied loads and internal osmotic pressure. Fluid flow plays a key role in this process, causing fluctuations in disc hydration and height. The objectives of this study were to quantify and model the axial creep and recovery responses of nondegenerate and degenerate human lumbar discs. Two experiments were performed. First, a slow compressive ramp was applied to 2000 N, unloaded to allow recovery for up to 24 h, and re-applied. The linear-region stiffness and disc height were within 5\% of the initial condition for recovery times greater than 8 h. In the second experiment, a 1000 N creep load was applied for four hours, unloaded recovery monitored for 24 h, and the creep load repeated. A viscoelastic model comprised of a “fast” and “slow” exponential response was used to describe the creep and recovery, where the fast response is associated with flow in the nucleus pulposus (NP) and endplate, while the slow response is associated with the annulus fibrosus (AF). The study demonstrated that recovery is 3-4X slower than loading. The fast response was correlated with degeneration, suggesting larger changes in the NP with degeneration compared to the AF. However, the fast response comprised only 10\%–15\% of the total equilibrium displacement, with the AF-dominated slow response comprising 40\%–70\%. Finally, the physiological loads and deformations and their associated long equilibrium times confirm that diurnal loading does not represent “equilibrium” in the disc, but that over time the disc is in steady-state.
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1. Introduction

The intervertebral disc is a hydrated fibrocartilage comprised of the gelatinous nucleus pulposus which is surrounded by the structured fiber-reinforced annulus fibrosus. Over the course of daily activities, the disc maintains a balance between externally applied loads and internal osmotic pressure. Fluid flow plays a key role in this process, causing fluctuations in disc hydration and height. Disc hydration influences disc mechanics, particularly the stiffness and the creep properties in axial loading (Koeller et al., 1984; Race et al., 2000; Costi et al., 2002; Johannessen et al., 2004). Therefore, quantification of the disc’s mechanical properties is highly dependent on loading history, which must be...