In Vivo MRI Quantification of Human Disc Compression and Flexion/Extension

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INTRODUCTION:

Disc function is mechanical, and measures of disc mechanical function are important to address spine function, degenerative disc disease, and low back pain. In vivo measures of disc mechanical function are needed, however the current standard in disc imaging is to acquire a single static image and classify the disc's appearance using qualitative integer scales for degree of degeneration. Current grading standards are acknowledged as insufficient to identify symptomatic discs for treatment. In addition, static T2 weighted MRI cannot provide mechanical function information – mechanics must be measured as the change following a load or deformation perturbation. Because the disc experiences significant compression and height loss throughout the day, and because flexion-extension postures are often associated with low back pain, these physiological mechanical perturbations have potential to be used to quantify disc mechanics in vivo. The objective of this study was to use MRI-based methods to quantify in vivo disc function by measuring changes in disc geometry and T2 relaxation time with diurnal changes and with controllable posture.

METHODS:

Volunteers aged 20–61 years were recruited in accordance with human subjects guidelines. Five subjects were young (20-28 years old) with no history of back pain except one subject with previous L4-L5 disc herniations within 2 years of this study, and three subjects were older (age ≥ 50) with variable histories. Each subject participated in one or both protocols: diurnal loading (n=7) or induced flexion/extension (n=4). The diurnal protocol consisted of two supine MRI sessions, the first < 1 hour after waking (AM) and the second in the late afternoon (PM). Between scans, subjects wore a ~10 kg backpack to magnify diurnal compression loading and went about their normal routines. Two subjects repeated the AM–PM diurnal protocol on two different days to evaluate repeatability. The induced flexion protocol consisted of an AM MRI in supine position immediately followed by an MRI in a flexion and/or extension position supported by pillows [1]. MRI in each position lasted approximately 1 hour and consisted of 4 lumbar spine scans: sagittal and coronal T2-weighted (T2-w) turbo spin echo (TSE) (3D, 0.5x0.5x5.0 mm, TR/TE=4540/124), mid-sagittal T2 map (2D, 0.6x0.6x5.0 mm, TR=3000, TE=13.6, 27.2,…81.6), and sagittal T1-weighted (T1-w) FLASH (3D, 0.5 x 0.5 x 3.0 mm TR/TE= 9.6/3.65).

Disc geometry (height, wedge angle, and 3D volume) was measured using the T1-w FLASH images. Disc height was measured by dividing disc area by anterior–posterior width in the mid-sagittal image [2]. Wedge angle was measured as the angle between superior and inferior endplates. 3D volume was measured from manual segmentations. T2 maps were calculated by fitting an exponential decay to intensity vs. TE time for each pixel in the nucleus pulposus (NP) [3]. Average NP T2 relaxation time was calculated from a central circular region of diameter = 3/4 the central disc height. The T2-w image was used for degenerative grading using the Pfirrmann scale. Measurements were qualitatively evaluated for the AM starting point and between conditions (diurnal: AM vs. PM; flexion/extension: supine vs. flexed/extended) due to the sample size.

RESULTS:

AM (Fig 1A): Disc geometry and NP T2 times taken in the AM were consistent within subjects. AM disc height and volume increased from L1 to L5 for all subjects, as expected, and in similar fashion between subjects. Within each subject AM disc height and volume were repeatable across different days. The herniated disc showed a clear drop in height, volume, and T2 compared to the pattern of the healthy discs in the same subject. Also, older subjects featured lower disc heights, volumes, and T2 times on all levels, particularly when normalized to subject height (not shown).

Diurnal (Fig 1B): Diurnal changes from AM to PM were more variable than AM parameters both within subjects and across subjects, although in almost all cases the disc height and volume decreased from AM to PM. Changes in height and volume (paired by day) were not correlated, suggesting that in some cases height loss was not all due to fluid flow out of the disc, but in some cases fluid redistributed and contributed to disc bulge. The T2 times, which are related to hydration (although other components such as proteoglycan also contribute) support this notion, as the change in T2 time from AM to PM was variable between the subjects and even within a subject on different days. Discs from older subjects displayed similar trends, but magnitudes of changes tended to be smaller. Average disc height loss was lower for older subjects and degenerate discs, and change in T2 had opposite signs (Fig 2).

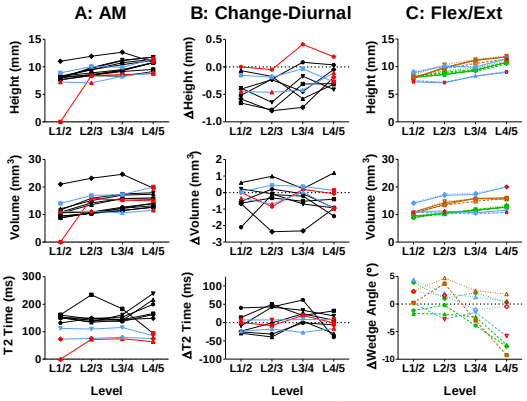

Figure 1: Geometry and T2 measurements for young (20-28 year, black), older (≥50 years, blue), and degenerate (23 and 61, red) discs. For flexion/extension, young are color coded for separation of subjects. Solid line = supine, dashed = flexion, dotted = extension.

Flexion/Extension (Fig 1C): Repeatability was high for all measures. Disc height and volume were unchanged with flexion/extension. Wedge angle increased for extension and decreased for flexion, as expected. Lower lumbar levels saw larger changes in flexion, while upper levels saw larger changes in extension. As with diurnal changes, older discs showed smaller changes in angle.

DISCUSSION:

The diurnal and flexion protocols both produced meaningful changes in disc geometry and T2, and degenerate discs displayed smaller changes compared to healthy discs (Fig 2). However, the same-subject variation in disc height, wedge angle, volume, and NP T2 for diurnal AM–PM changes was large, comparable to the differences between subjects (Fig 1B). Large differences between healthy and older or degenerated discs in the AM indicated protocol validity and potential utility to study degeneration and low back pain. Although AM disc state is consistent, it is static, and thus has limited potential to provide information about a disc's mechanical properties. A larger sample size will be needed to apply diurnal loading to study functional disc changes with age or degeneration.

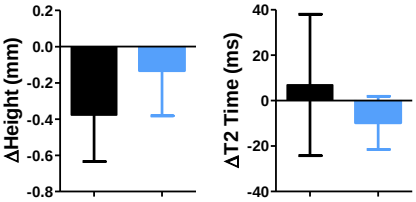

Figure 2: Average height and T2 change. Healthy = black, older/degen = blue

The flexion protocol showed promise as a controlled protocol to perturb the disc in vivo and measure its mechanical function. The protocol induced flexion specifically in the L3–L4 and L4–L5 discs (Fig 1C). The negligible change in disc height, volume, and T2 time is consistent with the limited time for water exudation and limited change in axial compression loads during flexion/extension. Because the flexion is imposed by changing spine posture it can be adjusted during imaging to achieve a specific target value.

SIGNIFICANCE:

Quantification of in vivo disc mechanics by using diurnal loading or prescribed posture changes has potential to improve our ability to identify, evaluate, and treat degenerative disc disease. Symptomatic discs may have aberrant mechanics; if so, in vivo measurements of mechanical function may, with continued development, facilitate diagnosis of pathological discs.

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