Accurate measurement of intervertebral disc height loss demonstrates the threshold of major pathological changes during the course of degeneration

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Target Audience: Clinicians and researchers interested in new diagnostic tools for spinal disc degeneration

Introduction: Intervertebral Disc (IVD) Degeneration is a universal and natural process.[1] As we age, our discs lose elasticity and begin to show signs of degeneration. Proteoglycans, a water retaining molecule, diminish within the degenerating discs. With the decrease in water, the discs lose their ability to resist compression and torque. Eventually the discs begin to lose height and structural integrity. The goal of this study was to quantify various pathological changes during the course of disc degeneration using MRI biomarkers. We proposed a method to quantify disc height loss with degeneration and suggested that the decrease in IVD height would correlate with other biomarkers of degeneration.

Methods: This study was approved by the IRB and written consents were obtained from 31 adult participants who took part in this study (age: 23–57y; mean 38y). Image data were acquired using a 3T GE Discovery MR750 (Waukesha,WI USA) MRI system. All images were acquired with a CTL-spine coil, FOV=310mm and 16-sagittal slices with 3mm thickness. A conventional T2 weighted (T2W) MRI was acquired using a FSE sequence with TR/TE=4500ms/104ms, ETL=24 and 1mm in-plane resolution. Diffusion Weighted Images (DWI) were acquired using a Single-Shot-EPI with TR/TE=2100ms/75ms, NEX=12 and 2.4mm in-plane resolution. One reference image (b=0) and a DWI with b=600sec/mm^2 were collected. Apparent Diffusion Coefficient (ADC) was calculated for each pixel and mean ADC was calculated in the Nucleus Pulposus (NP) of each lumbar IVD. A semi-quantitative measure was also derived from the T2W images. First, the mean voxel intensity in each NP was calculated. Then a region of interest (ROI) was drawn in a uniform region of the gray matter (GM) of the spinal cord and mean intensity was calculated in this ROI for each subject. Then the mean intensity in each disc is divided by the mean intensity in the spinal cord GM to obtain a metric that can be compared across subjects. Here we assumed that the inter-subject variations in spinal cord GM T2 signal would be minimal in subjects with no spinal cord anomalies.

The method for assessing disc height was modeled after a technique developed for rat tails.[2] Disc Height Index (DHI) helps minimize the inter-subject variations in overall size of the vertebral column, enabling inter-subject analyses. The proximal (PV) and distal (DV) vertebral body height and IVD height (DH) were measured from the anterior (1), middle (2), and posterior (3) portions of each respective disc level on T2W images (Fig.1). Then, DHI was determined using Eq.1.

$$DHI = 2 * \frac{DH1 + DH2 + DH3}{(PV1 + PV2 + PV3) + (DV1 + DV2 + DV3)} \quad (1)$$

A normative data was established for each lumbar disc by picking discs with no degeneration (Pfirrmann grade[3] 1 or 2) from the subjects. The DHI scores of all healthy discs at a particular level (e.g. L1/L2) were averaged so that each lumbar disc was assigned a mean and standard deviation, representing healthy population. Then, each disc of every subject was given a score based on how much its DHI deviated (in units of standard deviations, σ) from the mean DHI of corresponding disc in healthy population. These scores were binned in groups with 0.5σ increments and mean ADC and normalized T2 values were calculated for each bin.

Results: At deviations of up to 1.5σ below normative disc height, levels of ADC and normalized T2 intensity are maintained. Once disc compression reaches 1.5σ, there begins to be a massive drop in ADC and normalized T2 intensity (Fig.2 and 3). Pfirrmann degeneration scores also begin to increase after the 1.5σ mark. Interestingly, several discs whose DHI decreased more than 1.5σ were assessed by the radiologists as healthy or mildly degenerated (grade 2 or 3). However, ADC and normalized T2 intensity values suggested that these discs already began to undergo significant pathologic changes. Such a case is shown in Fig.4 and Table 1 with low ADC and T2 intensity with a Pfirrmann grade of 3 in the L3/L4 disc.

Discussion: Pfirrmann classification, which is the current gold standard, is based on visual inspection of T2W images. It is a subjective assessment because the rater inspects the changes in gross anatomical features reflected in T2W contrast. If Pfirrmann classification were supplemented by quantitative metrics, the physicians would be equipped with better information to diagnose the condition of the discs and plan the best treatment strategies. We demonstrated that DHI is a quick and easy measurement that correlated well with the stage of degeneration.

Conclusion: IVDs begin to show significant decrease in ADC and T2 intensity at 1.5σ below average disc height. This is a novel biomarker that could be used to identify degenerating discs that are approaching 1.5σ and possibly intervene before major pathologic changes occur.

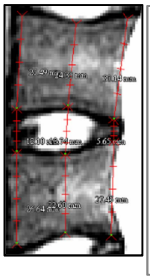

Fig.1 DHI measurements.

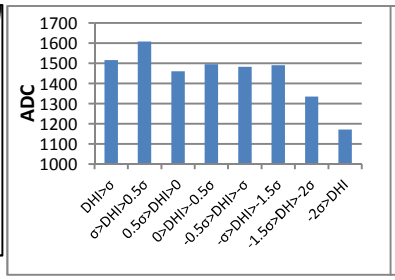

Fig.2. Disc ADC values for discs deviating from normative DHI.

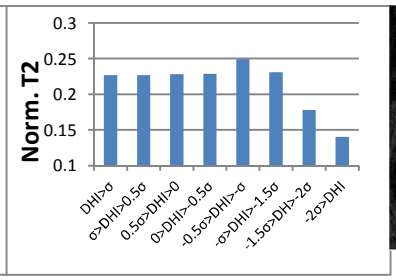

Fig.3. Normalized T2 values for discs deviating from normative DHI.

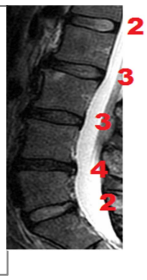

Fig.4. T2W image of lumbar spine. Pfirrmann grades labeled next to each disc

Table 1. Quantitative MRI measurements from intervertebral discs

Pfirrm. Grade	mean DHI-n*σ	ADC	Norm. T2
2	-0.08σ	1526	0.331
3	1.24σ	1290	0.237
3	2.23σ	872	0.196
4	2.15σ	1062	0.141
2	-0.05σ	1598	0.286

References: 1) Roh JS, *et al. Orthop Clin North Am.* 2005;36(3):255-262. 2) Issy AC, *et al. Braz J Med Biol Res.* 2013;46(3):235-244. 3) Pfirrmann CW, *et al. Spine*. 2001;26(17):1873-1878.