HUMAN DISC INTERNAL STRAINS UNDER COMPRESSION USING MAGNETIC RESONANCE IMAGING

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INTRODUCTION:

The intervertebral disc consists of the annulus fibrosus (AF), nucleus pulposus (NP) and endplate, which interact with each other for load support. However, most in vitro studies measure mechanical behaviors of the entire motion segment, with limited data for internal deformations. Internal disc displacements under load have been measured using invasive techniques such as metal beads or wires or by bisecting the disc (1, 2, 3). Recently magnetic resonance (MR) imaging non-invasively analyzed internal deformations under compression; however, strains could not be calculated (4). Therefore, little is known about the local internal disc strains, particularly deformations of the inner AF and the interactions between the NP, AF, and endplate. **The objective of this study was to non-invasively evaluate the internal disc strains under compression in intact human motion segments** using MR imaging and texture correlation, a technique validated to quantify internal strains from MR images of tendon (5).

METHODS:

Three human cadaveric lumbar spines were dissected and bone-disc-bone motion segments were prepared by removing the muscles and facet joints. T2-weighted images were performed on the lumbar spine for grading based on the Pfirrmann scale (6). Non-degenerate (n = 2; L1-L2 & L2-L3; 22 and 48 years old, grade 1 and 2, respectively) and moderately degenerate (n = 1; L2-L3; 77 years old, grade 3) motion segments were selected for this study.

The specimens were potted in polymethyl methacrylate bone cement while tissue hydration was maintained by covering specimens with saline-soaked gauze. The specimens were hydrated in a refrigerated PBS bath 18 hours before testing. A high resolution turbo spin-echo sequence was used to acquire a mid-sagittal MR image with a custom-built 55 mm square surface coil (3T magnet, 512 x 512 matrix size, 3 mm slice thickness, TR = 2000 ms, TE = 113 ms, 10 averages, total scan time <9 min). An initial 'reference' image was first acquired, with the sample fixed in place by a minimal tare load of 20 N. A compressive load of 1000 N was then applied by a custom non-magnetic device. This load is equivalent to 0.56 MPa, or approximately the load experienced when walking. The load was maintained for 15 min to allow for creep deformation, at which point the imaging sequence described above was repeated to acquire a 'deformed' image.

Internal deformations were calculated using texture correlation analysis with a custom written Matlab program (Matlab 7.0, Mathworks Inc.) (5). Two-dimensional Lagrangian strain components were calculated for the whole disc, AF, NP, and vertebral body from the initial and final nodal points using a finite element package (ABAQUS, Abaqus Inc). Outlying nodes with a displacement that deviated from the average by more than 2X the standard deviation were removed from the dataset (approx 6% of the total nodes).

RESULTS:

Using the high resolution turbo spin echo sequence, lamella were easily detected, giving the images enough texture to calculate strain (Fig 1). Compressive strain of the entire disc ranged from 4-6%, which is within physiological range. Average strains in the vertebral bone, NP, and anterior and posterior AF are shown in the Table. Compressive strain values in the bone were nearly zero (Table). The NP experienced outward radial bulge. The AF had an average of ~3% tensile radial strain (Table). Average shear strains were large at 8-9% in all three disc locations (Table).

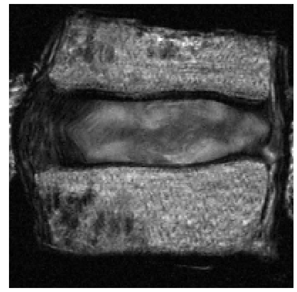

Figure 1: MRI of a human motion segment under 1000 N compression

	Axial	Radial	Shear
Bone	0.07 (0.08)	-0.05 (0.15)	1.37 (1.44)
NP	-1.65 (3.58)	-0.42 (2.53)	8.72 (5.96)
AAF	-2.40 (3.32)	2.96 (1.89)	9.28 (3.16)
PAF	-1.89 (3.34)	2.03 (0.65)	8.14 (1.80)

Table: Average strain (std dev) for the vertebral body, NP, anterior AF, posterior AF

Considerable spatial variation in strain was observed at each site (Fig 2), which was generally higher at the endplate. Larger axial compressive strains were noted along the disc midline (Fig 2A). Large peak tensile radial strains were observed in the AF (average peak strain of ~20%, Fig 2B). Similarly, high compressive radial strains were also noted. High shear strains were measured near the endplate (average peak strain of ~30%, Fig 2C).

DISCUSSION:

To the best of our knowledge, this is the first study to non-invasively measure internal disc strain. Local strains were measured for the vertebral bone, NP, and anterior and posterior AF. Outward bulging of the NP and AF was observed as reported by previous studies (1). Compressive displacement for this study was 1.1 mm, which is within displacement range previously measured by Seroussi et al. (2). High radial and shear strains were measured in the AF near the endplate, at the fiber insertion site, which may correspond to the site of AF tears that occur in degeneration. Tensile radial strains in the annulus may suggest a possible separation of lamella due to radial bulging.

Using strain analysis, this study has shown how the disc distributes compressive load through interactions between the nucleus, annulus and endplate. The technique used in this study can be used to measure the disc's response to more complex loading conditions and determine the changes with degeneration. The current study is limited by the number of specimens used; however, future studies will use a larger sample size in order to make more conclusions about internal disc strain changes with degeneration.

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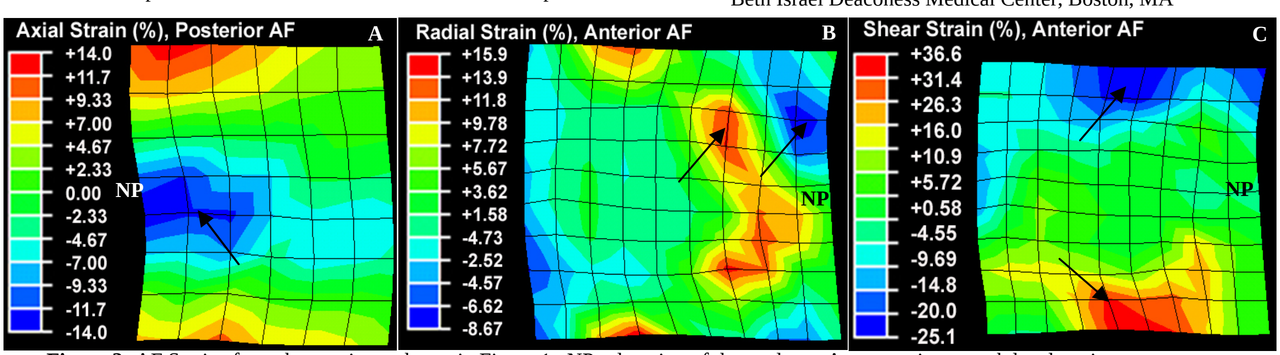

Figure 2: AF Strains from the specimen shown in Figure 1. NP = location of the nucleus. Arrows point to peak local strains.