Degeneration Alters Intradiscal Strains Under Compression and Bending Loading

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INTRODUCTION:

Disc degeneration is associated with a loss of internal structural integrity, including compromised material properties and localized fissures. Progress toward understanding and treating degeneration has been hampered because the inner workings of the disc annulus fibrosus (AF) and nucleus pulposus (NP) under load are not readily observed and the effect of degeneration on the internal stress-strain environment is unknown. While many in vitro studies have measured mechanics of the entire motion segment, there is limited data for internal deformations. Previous studies have measured internal disc displacements under load using invasive techniques such as metal beads or wires or by bisecting the disc.[1-3] We recently used magnetic resonance imaging (MRI) to non-invasively quantify internal disc strains of nondegenerate discs under axial compression.[4] **The objective of this study was to noninvasively quantify the effect of degeneration on internal disc strains under compression, flexion, and extension in human lumbar motion segments.** We hypothesize that degeneration will cause an increased magnitude in internal strains in all loading conditions.

METHODS:

Twelve human cadaveric lumbar spines were acquired and graded using T2-weighted MR images (grades 1.0-4.5). Motion segments were prepared by removing the muscles and facet joints from the L3-L4 and/or L4-L5 level (n = 20; 22-80 years), potting in bone cement and hydrating in a PBS bath prior to testing. Mechanical testing and imaging was performed as previously described.[4] A high resolution turbo spin-echo sequence was used to acquire a mid-sagittal MR image with a custom built surface coil (3T magnet, 234 µm/pixel, thickness = 3mm, TR/TE = 3000/113ms). A reference image was acquired, with the sample fixed in place by a tare load of 20N. A compressive load of 1000 N, which is analogous to the stress experienced when walking, was then applied by a custom non-magnetic device. Flexion and extension bending, combined with compression, was applied by inserting a 5º wedge into the device. The load was maintained for 20 min to allow for creep deformation, and the imaging sequence was repeated to acquire a deformed image. Samples were rehydrated between loading (≥ 8 hours).

Internal deformations were calculated using a commercially available software (Vic 2D, Correlated Solutions Inc.). The average radial, axial and absolute shear 2D Lagrangian strain components were calculated for the anterior and posterior AF (AAF & PAF, respectively) and NP. The average radial displacement was calculated for the inner and outer AF as the average displacement of the node from the posterior and anterior AF at mid-disc height. A paired t-test was performed to compare the axial strain in the AAF and PAF, and a Pearson's correlation was performed to compare strain components and degenerative grade in the AAF, PAF, and NP. Significance was set at $p \leq 0.05$.

RESULTS:

Under compression and bending, radial strains were observed as vertical bands of both tension and compression (arrows, Fig 1A). Peak axial strains tended to have horizontal bands with large compressive strains near the mid transverse plane (arrow, Fig 1C); shear strains were highest near the endplates (arrows, Fig 1E).

Significant correlations of strain components with degeneration were observed as described below. In the AAF, radial strain became more tensile under extension and compression (Fig 1B). Axial strain became more compressive under all loading conditions (r = -0.48, -0.46 & -0.76 for compression, flexion & extension, respectively; Fig 1D). Some nondegenerate samples (grades < 2.0), exhibited low axial tensile strains under extension (Fig 1C & D). Shear strain did not correlate with degeneration in the AAF. In the NP, radial strain did not correlate with degeneration. Axial strain became more compressive under extension and flexion (r = -0.59 & -0.45, respectively; Fig 1D), and shear strains decreased under extension (Fig 1F). In the PAF, no significant correlations with degeneration were observed. However, the average axial strain of the PAF was more compressive than the AAF under extension (-8.9 vs. -1.7%, respectively) and compression (-6.6 vs. -4.9%), and the opposite trend observed in flexion (-3.2 vs. -8.0%; p <0.03 for all).

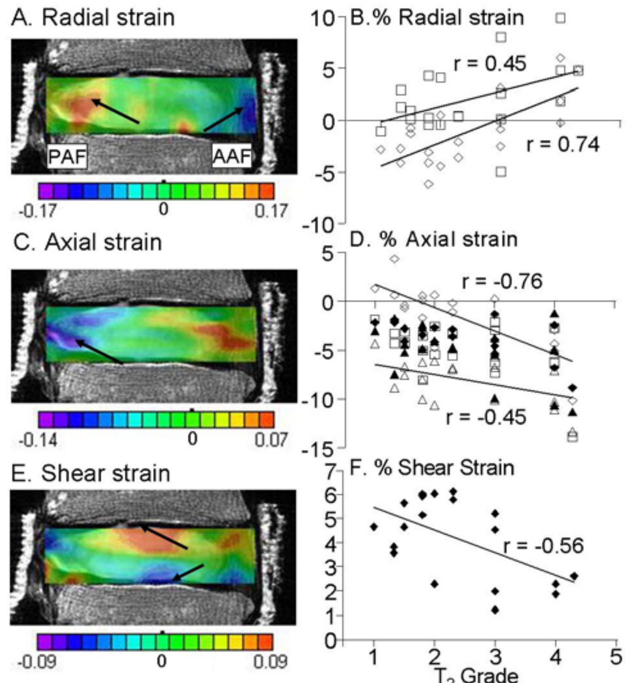

Figure 1: Strain maps of a nondegenerate disc under extension (left column) and correlation plots of average strains (right column) for A&B) Radial, C&D) Axial and E&F) Shear strains in (■) compression, (▲) flexion and (♦) extension of the AAF (open) and NP (filled).

The average radial displacement of the outer AF decreased with degeneration under flexion and compression (avg ± stdev = 0.44 ± 0.20mm & 0.47 ± 0.20mm, respectively; p<0.05). The radial displacement of the inner AF decreased under compression (0.29 ± 0.27mm; p = 0.02). There were no differences with average radial displacement in extension.

DISCUSSION:

This study evaluated degenerative effects on internal strains under physiological levels of axial compression, flexion and extension using a noninvasive MRI technique. The magnitude of the radial and axial strains in the AAF generally increased with degeneration under all loading conditions, while the shear strain was unchanged in the AAF and decreased in the NP. The average radial displacement and shear strains reported here are comparable to values reported in the literature (0.3 – 0.6mm & shear = 10%, respectively). [3, 5-6] Structurally, the disc bulges radially with degeneration; [7] however, the results presented here show that the change in radial displacement (or bulging) *under load* of degenerate discs is less than nondegenerate discs. This study is limited by the 2D imaging sequence used to acquire images and the long acquisition time required (12.5min). Therefore, images were only acquired at the mid-sagittal plane of the disc.

The observed increase in disc strains with degeneration suggests that the mechanisms of load distribution are greatly altered, likely due to the decrease in NP pressure that shifts more of the applied load to the AF. The increase in AAF radial strain and decrease in inner AF radial displacement with degeneration, together with the overall higher axial strain in the PAF compared to the AAF may be a result of, or a cause for, radial tears and circumferential delamination.[8] This study provides insights into internal disc strains and changes with degeneration, provides data useful for validation of finite element models, and provides a technique and baseline data for evaluating surgical treatment, such as discectomy or implants.

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