Quantification of Intervertebral Disc Tears by High-Resolution 3D MRI at 7T

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INTRODUCTION

The intervertebral disc (IVD) undergoes more extensive structural and compositional changes with age and degeneration than any other musculoskeletal tissue. With age and degeneration, tears appear within discs due to limiting diffusion of nutrients into the disc, alteration of chemical composition, and injuries. Disc tears are associated with low back pain [1,2]. The current clinical understanding of tears is that tears radiating to the outer third of the annulus fibrosis (AF) may cause low back pain [1]. However, detection of tears is difficult and quantification of their characteristics is not possible. Radial tears are often visualized under discography, however their location and orientation is difficult to determine [3]. Additionally, discography is an invasive procedure and involves exposure to radiation. The literature is replete with cadaveric studies using histology or gross sections showing a high incidence of AF tears [4,5]. However, shapes and sizes of tears are intricate, and even multiple histological sections cannot reconstruct the complex 3D tear geometry. As a result, quantitative characteristics of the 3D human AF tear remain largely unknown. The objective of this study is to provide a non-invasive MR technique for 3D visualization, measurement, and the ability to precisely locate disc tear orientation within a disc.

METHODS

Imaging: Fresh frozen lumbar human bone-disc-bone motion segments (age range 42-78, n=8), were imaged on a 7T Siemens whole-body MRI scanner using a custom-made transmit/receive RF coil [7]. A T2-weighted 3D turbo spin echo (TSE) pulse sequence was used (TE/TR = 100/1000 ms) producing 120 µm isotropic voxel resolution. Total imaging time per sample was in 45 minutes.

Analysis: OsiriX software (www.osirix-viewer.com) was used to measure total disc volume and perimeter, along with volume and path length of tears. Volume measurements were made by segmenting the entire disc and tear in each sagittal slice throughout the disc volume. Tear path length was measured by tracking the length of the tear throughout the disc. Disc perimeter was similarly determined from a single mid-axial slice.

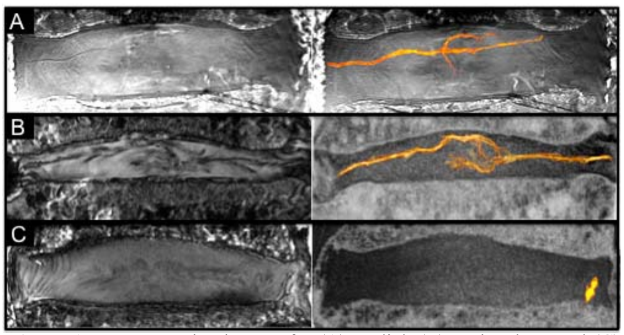

Figure 1: Representative images for (A) Radial, (B) Perinuclear, and (C) Circumferential tears. Left column shows raw TSE images and right column shows 3D fusion volume renderings of each tear throughout the whole disc, respectively.

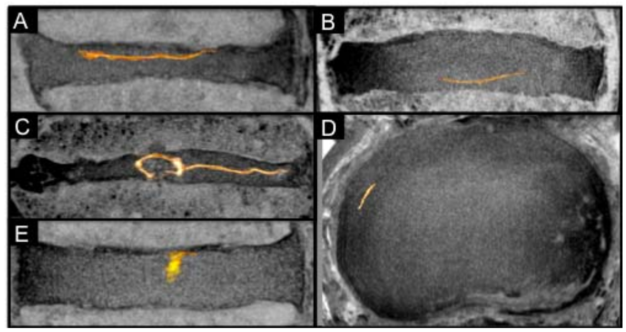

Figure 2: Volume fusion renderings of tears: (A-B) Radial tears, (C) Perinuclear/Radial tear, (D-E) Circumferential tear two different views of the same specimen.

RESULTS

A representative tear image for a radial, perinuclear, and circumferential tear is shown in Fig 1. Note, however, that even for these "classic" categories, the radial tear has additional tear offshoots in perinuclear and circumferential orientations. We were able to measure and quantify 3 radial, 3 circumferential and 2 perinuclear tears, and geometry of these are provided in Table 1. Tear volume and length varied widely among the 8 tears quantified. In both perinuclear tears, the NP clefting extended outwards into radial tears (Fig 1B). Several radial tears exhibited varying size circumferential tear off-shoots (Fig 1A). Volume rendering for several tears are shown in Figure 2.

DISCUSSION

To date, tears have primarily been quantified by performing histological sections, which can lead to artifacts during sectioning and lack the ability to accurately portray and quantify the complex and unique tear geometry. The presented method can accurately portray disc tears for biomechanical modeling of disc strains and other simulations. Also, the MR imaging technique presented here suggests that MRI might provide a tool for non-invasively detecting and quantifying disc tears, possible clinical application. While this method is currently not appropriate for in-vivo implementation due to the long imaging time, the ability to see structure without disrupting the native conditions of the intervertebral disc is essential for determining mechanisms of degenerative changes of IVD.

ACKNOWLEDGEMENT: Funded by NIH grant RC1 AR058450.

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Specimen Data						Volume		Length (cm)		Location
Fig Ref	Type	Age/Gender	Level	Pfirrmann	T1ρ	Disc (cm^3)	Tear (mm^3)	Disc Perimeter	Path Length	
2A	R, C	66/F	L1L2	4	41	10.82	15.00	13.63	1.62	L
1A	R	53/F	L2L3	3	NA	16.22	18.90	13.85	5.65	L
NA	R	78/F	L4L5	4	59	18.47	0.33	15.15	0.41	AL
2D/E	C	63/M	L2L3	3	60	20.61	12.90	16.49	2.06	TL
NA	C	42/F	L1L2	2	NA	11.48	0.92	12.54	0.28	A
1C	C, R	70/M	L4L5	3	43	25.30	14.10	16.57	0.79	PL
2C	PN, R	63/M	L3L4	3	67	14.96	193.50	16.48	8.25	TL
1B	PN, R	63/M	L4L5	4	39	13.90	58.90	16.48	5.84	TL

Table 1: Tear measurements. Type: R = radial, C = Circumferential, PN = perinuclear. Location: L = lateral, TL = trans-lateral, A = anterior, AL = antero-lateral, PL = postero-lateral