Magic Angle MR Microscopy and T2 Quantification of Intervertebral Discs Highlights the 3-Dimensional Collagen Structure

J. F. Dunn[1,2], T. Foniok[3], J. R. Matyas[4,5]

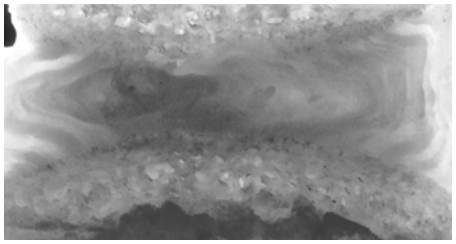
[1]Radiology, University of Calgary, Calgary, AB, Canada, [2]Experimental Imaging Centre, University of Calgary, Calgary, AB, Canada, [3]Institute of Biodiagnostics West, National Research Council, Calgary, AB, Canada, [4]Cell Biology and Anatomy, University of Calgary, Calgary, AB, Canada, [5]McCaig Centre for Joint Injury and Arthritis Research, University of Calgary, Calgary, AB, Canada

INTRODUCTION

MR images of hyaline cartilage reveal vertical striations, which correlate well with extracellular matrix structure revealed by fracture sectioning [1]. The contrast is dominated by T2 relaxation with little effect of T1 and water content [2]. Orientation-dependent changes in relaxation (magic angle effect) have been shown to highlight areas of ordered collagen structure [e.g., 1,2,3]. The intervertebral disk has a fibrous outer annulus fibrosus and an amorphous central nucleus pulposus. T2 maps, NMR microscopy and magic angle imaging, polarizing microscopy, and water content were used to describe the macroscopic structure of the intervertabral disc.

METHODS

Five bovine caudal discs were imaged at 9.4T using a Bruker console and a 35mm quadrature birdcage coil. A CPMG sequence was used to quantify T_2 *in vivo* (TR=2.5s, first and interecho spacing=0.007ms, 32 echoes, FOV=2.25 cm, matrix=256, slice thickness=1 mm, NT=4). MRI microscopy was done with TR/TE=2.5/0.025s and pixel resolution of 44x44x1000µm. The read direction was consistent to ensure consistent chemical shift. Fat saturation was used in a subset of high resolution images. Images were collected with the vertebral endplate perpendicular to Bo, and again when rotated 55°C to Bo. Decay curves were fit to a single exponential. Water content was estimated with MR by extrapolation of the relative SI to zero TE, by measuring wet/dry weights across the disc. Samples were cryofractured, photographed, and sectioned for polarized light microscopy.



RESULTS

Figure 1: Photograph of the cross section of the intervertebral disc. Prominent bands are seen extending between the vertebral endplates in the annulus.

Prominent striations are observed on the T2w MRI and on the T2 maps (Fig. 2,3). Striations corresponded to areas of highly ordered collagen. This was confirmed by rotating through 55° with respect to Bo and observing that the dark areas increase in both SI and T2 (Fig. 2,3) On rotation, the dominant changes in T2 are in the annular regions. Photographs of fractured specimens show a macroscopic structure of a similar size to that of the striations (Fig. 1). The average T2 of the nucleus shows little change, but both axial and coronal high resolution images do indicate that there is some oriented structure in the nucleus. A transect of water content measured physically and with MRI showed slightly higher water content in the nucleus.

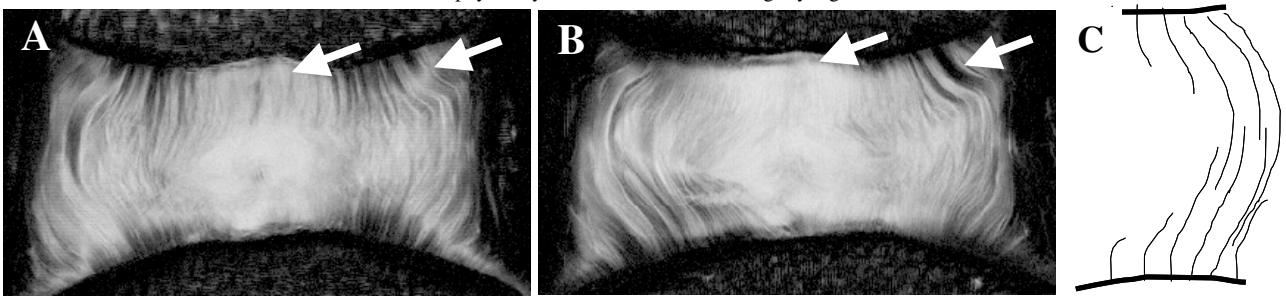


Figure 2: High resolution T2w coronal MRI of vertebral disc: A) 0° wrt Bo; B) 55° wrt Bo. Arrows indicate SI changes with rotation; and C) model of collagen consistent with the observed changes in SI.

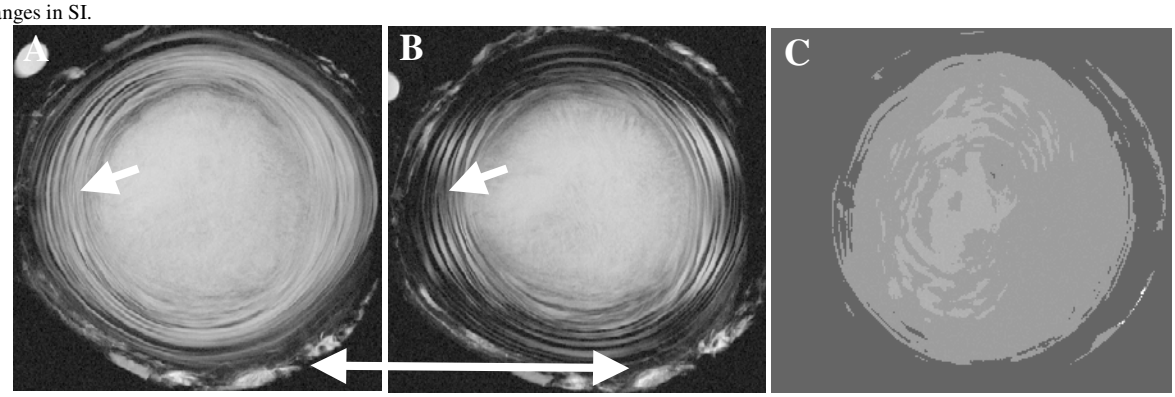


Figure 3: Axial MRI of discs: A) 0° wrt Bo; B) 55° wrt Bo. The long arrow is a reference marker. Short arrows point to strong magic angle effects; and C) T2 map, showing a sample with oriented circular structure within what is considered the nucleus pulposus.

DISCUSSION

This work confirms that the laminar structure of the annulus fibrosis that has been observed with polarized light microscopy [4] can be detected by MRI. The MRI images provide additional novel information on the 3D macroscopic organization on the whole disc. Based on magic angle effects, there are highly oriented layers in the annulus that extend from bone to bone and bulge outward from the middle. The vertical striations arising from the bone surface (Fig. 1,2) are analogous to those observed in articular cartilage, implying a strong tethering of collagen fibres to the bone [1,2]. The annular striations are suggestive of either a spring-like mechanism (analogous to a vehicle's McPherson strut where the shock absorber is located within the spring) or a physical containment of the highly hydrated, incompressible, and amorphous nucleus (i.e., like a jelly donut) [5]. MR microscopy also shows a texture in the nucleus which has not been observed by other methods and which may be used as an early marker of disc degeneration.

REFERENCES

1. Goodwin DW, Wadghiri YZ, Zhu H, Vinton CJ, Smith ED, Dunn JF. *Am J Radiol* 2004; 182:311-318.
2. Goodwin DW, Wadghiri YZ, Dunn JF. *Acad Radiol* 1998; 5:790-798.
3. Mosher TJ, Smith H, Dardzinski BJ, Schmithorst VJ, Smith MB. *Am J Roentgenology* 2001; 177(3):665-669.
4. Sahlman J et al. *Spine* 2001; 26:2558-2565.
5. Iatridis JC, Setton LA, Foster RJ, Rawlins BA, Weidenbaum M, Mow VC. *J Biomechanics* 1998; 31:535-544.