In Vivo MRI of the Cartilaginous Endplate of the Intervertebral Disc

S. M. Moon[1,2], J. H. Yoder[1], D. M. Elliott[1], F. W. Wehrli[2], and A. C. Wright[2]
[1]Department of Orthopaedic Surgery, School of Medicine, University of Pennsylvania, Philadelphia, PA, United States, [2]Laboratory for Structural NMR Imaing, Department of Radiology, University of Pennsylvania Medical Center, Philadelphia, PA, United States

INTRODUCTION

Intervertebral disc degeneration is considered one of the key causes of back pain. The intervertebral disc has three major structural components: nucleus pulposus, annulus fibrosus, and cartilaginous endplates (CEP). Many studies have been reported on anatomy, mechanics, and chemistry of the nucleus and annulus [1-4] while very little is known about the MR characteristics of the CEP because it is very thin (~600μm) and difficult to image and recognize on routine MR exams (e.g., Fig. 3d: mid-sagittal T2-weighted scan for *Pfirrmann grading*). Functionally, the CEP is considered a gateway for nutrient transport from blood vessels into the central disc [2]. As degeneration progresses, the CEP becomes sclerotic and loses contact with blood vessels, providing less nutrition to the disc as well as to the CEP itself. As a result, proteoglycan content decreases within the disc, which in turn, causes a loss of hydration and osmotic pressure of the disc matrix [3,4]. The loss of the CEP is also associated with calcification and rupture (e. g. Schmorl's nodes, a protrusion of disc into the adjacent vertebral body). Therefore, visualizing CEP or measuring water content of the CEP is important for the evaluation of disc degeneration. Recently, ex-vivo MR imaging of the CEP has been reported [5], however, imaging the CEP in-vivo is challenging due to the CEP's thinness and low SNR, and is limited by the subject's tolerance and movement. In this study, we have used a 3D FLASH sequence to visualize the CEP, first in specimens and then in volunteers, in order to assess the feasibility of MRI characterization of the CEP for in-vivo studies of disc degeneration.

METHODS

To determine pulse sequence parameters for optimal image contrast for the CEP, T1 and T2 parameter maps at 3T and 7T were measured of specimens from donors with healthy and degenerated discs. These were followed by high-resolution scans of volunteers at 3T using standard vendor-supplied RF coils.

Ex-vivo study: Human cadaveric lumbar spine motion segments were used to obtain high spatial and temporal resolution T1 and T2 maps as well as to develop protocols to visualize CEPs for both 3T and 7T. For T1 andT2 maps, 2D spin echo images with 200μm in-plane resolution at 12 different echo times were acquired of both moderately healthy (Pfirrmann grade 2.67) and severely degenerated (Pfirrmann grade 5) discs for comparison. These T1 and T2 values enabled optimization of the scan protocol for CEP staging using 3D FLASH, based on the FLASH signal equation,

$$S = A\sin\alpha\left[(1-\exp(-TR/T1))/(1-\cos\alpha\exp(-TR/T1))\right]$$ [6].

In-vivo study: Volunteers were imaged on a Siemens 3T scanner (TIM Trio), using the Siemens spine array RF coil and parameters were optimized from the ex-vivo scans. In each session, routine T2-wighted mid-sagittal images were acquired to evaluate Pfirrmann grade, followed by 3D FLASH images with TE=3.7ms, TR=9ms, flip angle=20°, voxel=0.5x0.5x5mm^3. The phase-encoding direction was chosen to be head-foot to displace respiratory motion artifacts away from the spine.

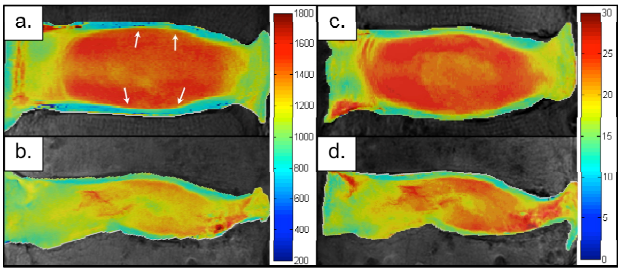

Fig. 1. T1 and T2 maps (left and right) at 7T of healthy (a, c) and degenerated (b, d) discs (units in ms). Arrows point to CEP

	T1 (healthy/degenerate)		**T2** (healthy/degenerate)	
	3 T	7 T	3T	7T
AF	900 / 750	1270 / 1100	35 / 25	21 /19
NP	1250 / 1020	1510 / 1300	47 / 31	25 / 21
CEP	540 / 570	775 / 840	19 / 18	14 /13

Table 1. Mean T1 and T2 values from ROIs drawn on the maps of Fig. 1 within the AF, NP and CEP. (units in ms)

RESULTS

Fig. 1 and Table 1 show results of T1 and T2 maps. As expected, T1 values are increased and T2 values decreased at 7T compared to 3T. Degenerated disc appears to have shorter T2 than relatively healthy disc, and T2 values of NP match those reported previously [7]. Simulation results show that a flip angle near 20° and TR of 9-18ms give optimal CEP contrast for imaging at 3T (Fig. 2). TE, imaging matrix, and other parameters were determined as the scanner allowed in order to achieve the shortest scan time. This resulted in 3-minute ex-vivo scans for the specimens, and 7-minute in-vivo imaging of the lumbar spine. Results of ex-vivo and in-vivo scans are shown in Fig. 3.

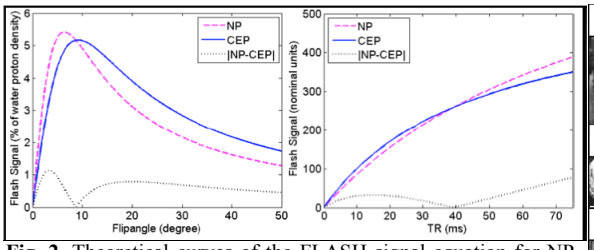

Fig. 2. Theoretical curves of the FLASH signal equation for NP and CEP at 3T: (left) signal vs. flip angle, (right) signal vs. TR.

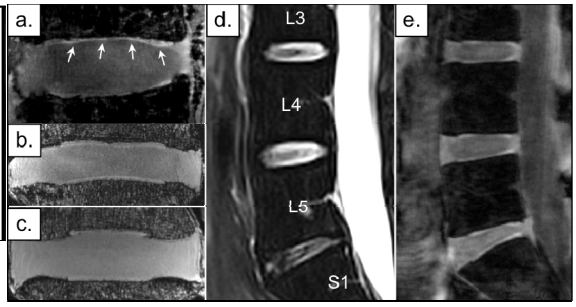

Fig. 3. Ex-vivo (a-c) and in-vivo (d,e) MR images. Endplates (arrows) are brighter than nucleus pulposus and can be distinguished clearly in sagittal (a) and coronal (b,c) images. (d) Routine in-vivo T2-weighted mid-sagittal image for comparison, CEP cannot be clearly visualized. (e) In-vivo 3D FLASH using optimized parameters.

DISCUSSION

To the best of our knowledge, this is the first study to report T1 and T2 maps specifically of the CEP, and these were then used to assess the feasibility of in-vivo studies targeting the CEP. Quantitative imaging the CEP in vivo is a critical step toward investigating its role in disc degeneration. The degenerated disc in Fig. 1 had shorter T2 for NP, in agreement with reported values [7], but T2 for CEP was not significantly different from that of the healthy disc. However, T1 differences were apparent both for NP and CEP. Hence, contrast between NP and CEP in T1-weighted images might prove useful for the evaluation of disc degeneration. Also, since T1 and T2 of AF are closer to those of CEP than to those of NP, careful choice of imaging parameters is needed to distinguish the CEP from AF. Furthermore, due to both the thinness and curvature of the CEP, voxel size must be chosen to avoid artifacts such as Gibbs ringing and partial volume averaging. In conclusion, in-vivo studies of the CEP are feasible at 3T. With specialized RF coils in-vivo studies may be possible at 7T also, which would be more beneficial in terms of SNR and may permit direct characterization of the 3D morphology of CEP in disc degeneration and low back pain.

ACKNOWLEDGEMENT: Funded by NIH grant RC1 AR058450.

REFERENCES: [1] Urban JPG et al., Arthritis Research & Therapy, 5(3):120-130, 2003. [2] Roberts S et al., J Ortho Res,11:747-757, 1993. [3] Lyons et al., Biochem Biophys Acta, 673:443-453, 1981. [4] Raj PP, Pain Practice, 8(1):18-44, 2007. [5] Moon SM et al., Proceedings of the 57th ORS meeting: p.174, Jan. 2011. [6] Helms et al., MRM, 59:667-672, 2008. [7] Blumenkrantz, MRM, 63:1193-1200, 2010.