The angular dependence of T1ρ relaxation in normal and abnormal patellae with histological correlation

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INTRODUCTION

Both T_2 and $T_{1\rho}$ have been employed to evaluate articular cartilage degeneration. The magic angle effect in T_2 relaxation is well understood [1]. However, the literature regarding $T_{1\rho}$ relaxation mechanisms is inconsistent. Some researchers reported much reduced or negligible magic angle effect in $T_{1\rho}$ relaxation [2-4]. For example, Akella et al. reported that spin-lock RF pulses can reduce the laminar appearance [2]. Li et al. investigated the effect of angular orientation on $T_{1\rho}$ and T_2 values, and found little angular dependence [3]. Duvvuri et al. suggested that proton exchange between NH and OH groups of proteoglycans and the tissue water might be an important contributor to $T_{1\rho}$ relaxation [4]. Other researchers have reported significant magic angle effect in $T_{1\rho}$ relaxation. For example, Mlynarik et al. found that $T_{1\rho}$ was more orientation and spin-lock field strength dependent in the deep radial zone than in the transitional zone, and concluded that the dominant $T_{1\rho}$ relaxation mechanism at $B_0 \leq 3T$ is dipolar interaction [5]. Menezes et al found that changes in collagen concentration alone could fully account for the variation in $T_{1\rho}$ seen in human tissue [6]. Furthermore, magic angle effects in normal vs. abnormal cartilage are unknown. In this study we aimed to systematically evaluate the magic angle effect on T_2 and $T_{1\rho}$ in histological confirmed normal and abnormal cartilage at 3T.

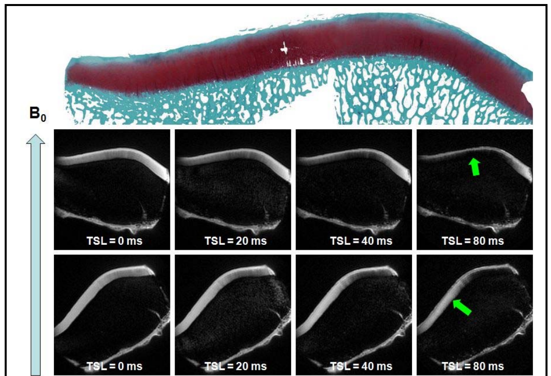

Fig 1 *Histology (1st row) and 2D spiral $T_{1\rho}$ imaging of a patella at 0° and 40° to B_0. Signal from histology confirmed normal cartilage shows strong angular dependence (arrow).*

MATERIALS AND METHODS

Eight cadaveric human knee patellae were sectioned into transverse slabs of 5-8 mm thickness and stored in a phosphate buffered saline (PBS) soaked gauze at 4°C prior to MR imaging on a clinical whole body GE scanner. A 3-inch receive only surface coil was used for signal reception. The patella samples were placed in perfluorooctyl bromide (PFOB) solution to minimize susceptibility effects at tissue-air junctions. A single slice at the center of each patella sample was imaged. The imaging protocol was shown in **Table 1** (each sample was acquired at six angles relative to the B_0 field) [7, 8].

	FOV (cm)	TR (ms)	TE or TSL (ms)	Recon Matrix	Slice (mm)	BW (kHz)	Angular Orientations relative to B0	Scan time (hours)
2D Spiral T1rho	5	2000	0, 10, 20, 40, 80	256×256	2	125	0°,20°,40°,60°,80°,100°	~3
3D MAPSS T1rho	5	15	0, 10, 20, 40, 80	256×256	2	62.5	0°,20°,40°,60°,80°,100°	~3
2D CPMG T2	5	2000	10,20,30,40,50,60,70,80	256×256	2	62.5	0°,20°,40°,60°,80°,100°	~3

Table 1 *Imaging protocol for cadaveric human patellae.*

After MRI the patellae slabs were immediately fixed in Z-Fix and sent for histopathology. 2-4 regions of interest (ROIs) per patella were chosen for correlation with histopathology and MRI measurements of $T_{1\rho}$ and T_2. Each ROI was given a Mankin score ranging from 0 to 14. Only regions with a Mankin score of equal or less than 7 were used for correlation analysis. Cartilage regions with a Mankin score of less than 2 were considered normal, and regions with a Mankin score higher than 2 were considered abnormal. $T_{1\rho}$ and T_2 were determined using nonlinear least square curve fitting of average signal intensities from normal and abnormal regions with three layers (10% superficial, 60% middle, 30% deep) as well as a global ROI for the whole region. Image registration was performed before data analysis to ensure that ROIs were identically located on images obtained at different angles and sequences.

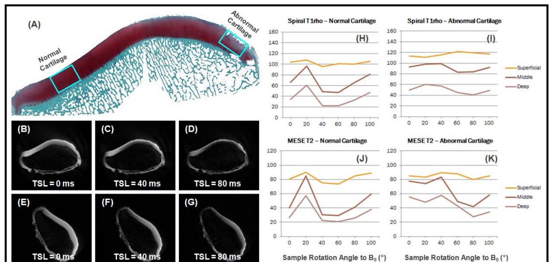

Fig 2 *Histology (A) and spiral $T_{1\rho}$ images at 0° with TSL=0 ms (B), 40 ms (C), 80 ms (D), and at 40° with TSL=0 ms (E), 40 ms (F) and 80 ms (G). $T_{1\rho}$ and T_2 for normal (H, J) and abnormal (I, K) cartilage show strong angular dependence.*

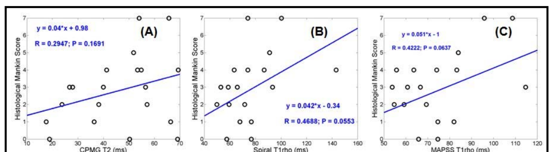

Fig 3 *Low to moderate correlation was seen between T_2 (A), spiral $T_{1\rho}$ (B), MAPSS $T_{1\rho}$ (C) and the Mankin score.*

RESULTS AND DISCUSSION

Figure 1 shows selected 2D spiral $T_{1\rho}$ images of a histologically confirmed normal patella at 0° and 40°. The middle and deep layers of articular cartilage showed dramatic signal change with angular orientation. The superficial layers show much less signal change with angular orientation.

Figure 2 shows spiral $T_{1\rho}$ images of another patella with histologically confirmed normal and abnormal regions, which again shows strong magic angle effects.

Figure 3 shows the correlation between T_2, spiral $T_{1\rho}$ and MAPSS $T_{1\rho}$, and histopathological grading. There is a low correlation between T_2 and the Mankin score (Rho = 0.29; P = 0.17), a moderate correlation between 2D spiral $T_{1\rho}$ (Rho = 0.47; P = 0.06), 3D MAPSS $T_{1\rho}$ (Rho = 0.42; P = 0.06) and the Mankin score. The low correlation is most likely due to the strong magic angle effects in both the measured T_2 and $T_{1\rho}$ relaxation times.

Table 2 shows the magic angle effects in different layers of the normal and abnormal cartilage. T_2 values were increased by 156% for normal cartilage, and 104% for abnormal cartilage. 2D spiral $T_{1\rho}$ values were increased by 72% for normal cartilage and 63% for abnormal cartilage. 3D MAPSS $T_{1\rho}$ values were increased by 67% for normal cartilage and 53% for abnormal cartilage. Abnormal cartilage shows a slightly lower (4~10%) magic angle effect.

		Normal Cartilage				Abnormal Cartilage			
		Superficial (10%)	Middle (60%)	Deep (30%)	Global ROI	Superficial (10%)	Middle (60%)	Deep (30%)	Global ROI
2D Spiral T1rho	Max	105.7	88.4	59.2	81.2	109.7	96.9	66.4	86.9
	Min	86.6	50.7	23.5	47.1	88.7	60.1	24.8	53.3
	Ratio	123%	174%	252%	172%	124%	161%	268%	163%
3D MAPSS T1rho	Max	114.9	98.1	65.1	89.8	134.0	104.9	69.3	92.1
	Min	94.1	58.3	27.4	53.8	105.2	67.7	28.8	60.1
	Ratio	122%	168%	238%	167%	127%	155%	241%	153%
2D CPMG T2	Max	85.3	78.4	55.1	71.5	93.7	75.2	53.4	69.4
	Min	66.6	28.7	21.4	27.9	66.2	38.2	17.6	34.1
	ratio	128%	273%	258%	256%	142%	197%	303%	204%

Table 2 *2D spiral and 3D MAPSS $T_{1\rho}$ and CPMG T_2 for the superficial, middle and deep layers, as well as a global ROI in both normal and abnormal cartilage. There is an obvious magic angle effect for both $T_{1\rho}$ and T_2. A slightly reduced magic angle effect was observed in abnormal cartilage.*

CONCLUSIONS

T_2 and $T_{1\rho}$ in both normal and abnormal cartilage are strongly affected by the magic angle effect, which increased T_2 by 100-150% and $T_{1\rho}$ by 60-75%. The increases were much higher than these typically seen in degeneration (usually <30%) [9], leading to a low to moderate correlation between T_2 and $T_{1\rho}$ with histological grading.

References 1. Xia Y, et al., JMRI 1997. 2. Akella SVS, et al, MRM 2004. 3. Li X, et al, MRI 2011. 4. Duvvuri U, et al., Osteoarthritis Cartilage 2002. 5. Mlynarik V, et al., JMR 2004. 6. Menezes et al, MRM 2004. 7. Li X, et al, Osteoarthritis Cartilage 2007. 8. Li X, et al, MRM 2008. 9. Mosher TJ, et al, Radiology 2011.