Magic angle effect plays a significant role in T1rho relaxation in articular cartilage
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INTRODUCTION
In recent years quantitative imaging of the knee joint in osteoarthritis (OA) has focused on two particular biomarkers: T1ρ and T2 (1-8). T1ρ has been shown to be sensitive to proteoglycan (PG) depletion (4-7). T2 has been shown to be sensitive to collagen matrix degradation (1). The magic angle effect is a potential confounding factor in T2 and T1ρ evaluation of joint tissue degeneration (3). The ordered collagen fibers in joint tissues are associated with residual dipole-dipole interactions which are modulated by (3cosθ-1), where θ is the angle between the fiber orientation and B0 field (2). The interactions are minimized when the fibers are oriented 55° or 125° (the magic angle) to B0 and 3cosθ-1 is near zero. At these angles, fiber T1ρ and T1ρ values are often increased relative to these obtained with fibers parallel to B0. However, the literature regarding T1ρ relaxation is inconsistent, with some groups finding strong residual dipolar interaction (3), and other groups reporting a much reduced magic angle effect (4). In this study we aimed to evaluate the effect of sample orientation on T1ρ and T1ρ values of cadaveric human patellae.

MATERIALS AND METHODS
Eight cadaveric human knee patellae were harvested for this study. After harvesting, a transverse slab of 5-8 mm thickness was cut 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 body coil was used for signal excitation). 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 included the following three sequences: 1) a 2D CPMG sequence with eight echoes (10 to 80 ms) for T2 measurement; 2) a 2D spin-locking spiral sequence for T1rho measurement; 3) a 3D magnetization-prepared angle-modulated partitioned-k-space SPGR snapshots (3D MAPSS) sequence for T1rho measurement; Typical imaging parameters included: field of view (FOV) = 5 cm, matrix = 256x256, 2 mm slice thickness, spin-lock time (TSL) = 0, 10, 20, 40, 80 ms for 2D/3D T1rho measurement, and TE = 10, 20, 30, 40, 50, 60, 70, 80, 100 ms for CPMG T2 measurement. The same imaging protocol was applied to each sample at six different angular orientations: 0°, 20°, 40°, 60°, 80° and 100° relative to the B0 field. T1rho/T2 values were determined using nonlinear least square mono-exponential curve fitting of average signal intensities from three regions (medial, apex lateral) with three layers (10% superficial, 60% middle, 30% deep) for each region. Image registration was performed before data fitting of average signal intensities from three regions (medial, apex, deep) for each region. Image registration was performed before data analysis to ensure that ROIs were identically located on images obtained at different angles and sequences.

RESULTS and DISCUSSION
Figure 1 shows selected CPMG T2 and spiral T1ρ images of a patella at two angular orientations relative to the B0 field. The middle and deep layers of articular cartilage (arrows) show dramatic signal change: near zero signal when the collagen fibers are oriented parallel to the B0 field while a high signal is seen when the fibers are oriented near the magic angle.

Figure 2 shows quantitative analysis of CPMG T2 and spiral T1ρ values of the superficial, middle and deep layers of articular cartilage in the medial region (arrows in Figure 1). T2 values were lowest (~12.0 ms) when radial fiber were near 0° to B0, increased to a maximum at ~55° (~65.3 ms) and decreased to a local minima at 90° (~27.7 ms). T1ρ values exhibited similar angle dependency: ~33.2 ms near 0°, ~82.1 ms near the magic angle, and ~59.6 ms near 90°. MAPSS T1ρ values showed similar trend (results not shown).

Over average eight patellae, T2 values were increased by 231.8% (72.2% for superficial, 237.6% for middle, and 187.9% for deep layers) while T1ρ values were increased by 92% (31.7% for superficial, 69% for middle and 140% for deep layers) near the magic angle. The magic angle effect on T2 is well known. Our study indicates that the magic angle effect also plays a significant role in T1ρ relaxation.

CONCLUSIONS
Quantitative MRI, including T2 and T1ρ, is increasingly used for objective evaluation of musculoskeletal tissues. Results from this study show that the fibril or fiber-to-B0 angle may be higher than changes associated with degeneration, and this needs to be considered during quantitative T2 and T1ρ MRI evaluation of articular cartilage.

REFERENCES