

Reproducibility of Magnetic Resonance $T_{1\rho}$ and T_2 Relaxation Time and Morphological Measurements of Articular Hip Cartilage at 3T

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Introduction

$T_{1\rho}$ and T_2 relaxation time mapping are two magnetic resonance (MR) imaging techniques that have recently emerged as potential markers of early biochemical cartilage degeneration in osteoarthritis (OA). $T_{1\rho}$ relaxation time is inversely correlated with proteoglycan content, while T_2 relaxation time is positively correlated with tissue hydration and collagen anisotropy. While these MRI techniques have been investigated extensively in the knee, their application to hip has been relatively limited, in part due to signal-to-noise ratio constraints associated with the deeper position of this joint (1).

Femoroacetabular impingement (FAI) is known to play a pathogenic role in the development of hip OA (2). FAI is often characterized by an anatomic deformity at the femoral head-neck junction, reflected by the alpha angle, a measure of the asphericity of the femoral head. The purpose of this pilot study is to determine the reproducibility of MR measurements of hip cartilage thickness, volume, $T_{1\rho}$ and T_2 relaxation times, as well as that of alpha angle.

Methods

MR imaging was performed at 3 T (GE Healthcare, Waukesha, WI) on the hips of 7 healthy volunteers and 3 subjects with FAI using a cardiac coil (GE Healthcare, Waukesha, WI). High resolution, fat-suppressed, sagittal 3D SPGR MR images (ST = 1.5 mm, res = 0.27 mm, FOV = 14 cm) were acquired to assess cartilage morphology, and $T_{1\rho}$ (TSLs = 0, 15, 30, and 45 ms, ST = 3 mm, res = 0.54 mm, FOV = 14 cm) and T_2 (TEs = 0, 10.4, 20.8, and 41.7 ms, ST = 3 mm, res = 0.54, FOV = 14 cm) images were acquired to measure relaxation times. For 3 of the subjects (2 volunteers and 1 patient), oblique axial T_2 FSE (ST = 3 mm, res = 0.49, FOV = 14 cm) images were acquired for alpha angle measurement. To evaluate reproducibility, all images for a subset of subjects (all males, mean age = 23 ± 3.6 years, n = 4) were acquired twice and subjects were repositioned in between scans. $T_{1\rho}$ images were acquired for a total of 10 subjects (7 controls and 3 patients), a subset of whom had SPGR images (5 controls, 2 patients) and T_2 images (4 controls, 2 patients). Articular cartilage was segmented from the SPGR images using a spline-based, semi-automatic technique and was defined in three regions: acetabulum, femur, and the combination of the two. The $T_{1\rho}$ and T_2 maps were rigidly registered to the SPGR images and the segmented regions of interest (ROIs) were then superimposed on the maps. Alpha angle was measured between two splines emanating from the center of a circle superimposed on the femoral head, one drawn parallel to the femoral neck, and the other intersecting the anterior point at which the femoral head diverged from the circle (Fig. 1). All measurements were performed by the same individual. Reproducibility was determined by calculating the coefficients of variation (CV_{RMS}) for cartilage thickness, volume, $T_{1\rho}$ and T_2 , and alpha angle measurements (3). Correlations were assessed by Spearman's ρ using JMP 8.0 (SAS Institute, Cary, NC, USA).

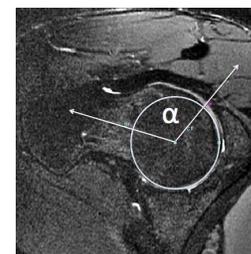


Figure 1. The alpha angle of an FAI patient shown on an oblique axial T_2 FSE image.

Results

Representative $T_{1\rho}$ maps from a control and FAI patient are shown in Fig. 2. Reproducibility of cartilage thickness, volume, $T_{1\rho}$ and T_2 measurements ranged from 0.3-4.7% (Table 1) and that of alpha angle ($CV_{RMS} = 4.69\%$) also fell in this range. Table 2 shows the mean cartilage thickness, volume, $T_{1\rho}$ and T_2 relaxation times, and alpha angle for the controls and subjects with FAI. While no significant correlation was observed between cartilage thickness and $T_{1\rho}$ or T_2 relaxation times, $T_{1\rho}$ and T_2 relaxation times were positively correlated ($r = 0.58$, $p < 0.015$).

| Region | Thickness [mm] | Volume [mm ³] | $T_{1\rho}$ [ms] | T_2 [ms] |
|------------|----------------|---------------------------|------------------|------------|
| Acetabulum | 0.27% | 0.69% | 3.32% | 4.61% |
| Femur | 0.47% | 0.75% | 1.19% | 3.07% |
| Combined | 1.22% | 0.70% | 1.69% | 3.68% |

Table 1. Reproducibility results (reported as CV_{RMS}) of MRI morphological and relaxometry measurements of the hip joint at 3 T.

Table 2. Means of the morphological and relaxometry measurements of the hip joint at 3 T. Note: alpha angle is not associated with any cartilage ROI.

| Subjects | Region | Thickness [mm] Global Mean | Volume [mm ³] Global Mean | $T_{1\rho}$ [ms] | T_2 [ms] | Alpha Angle [°] Mean |
|----------|------------|-------------------------------|--|---------------------------------|---------------------------------|-------------------------|
| | | | | Global Mean (Min, Max) | Global Mean (Min, Max) | |
| Controls | Acetabulum | 1.10 mm (n = 5) | 1119.14 mm ³ (n = 5) | 39.01 ms (32.81, 52.41) (n = 7) | 31.50 ms (28.60, 34.59) (n = 4) | 42.70° (n = 2) |
| | Femur | 1.12 mm | 1588.24 mm ³ | 38.91 ms (34.69, 48.23) | 31.02 ms (28.56, 33.20) | |
| | Combined | 2.03 mm | 2807.74 mm ³ | 39.07 ms (34.01, 50.27) | 31.27 ms (28.63, 33.53) | |
| Patients | Acetabulum | 1.16 mm (n = 2) | 1634.58 mm ³ (n = 2) | 38.24 ms (35.78, 41.59) (n = 3) | 33.17 ms (31.26, 35.08) (n = 2) | 111.04° (n = 1) |
| | Femur | 1.24 mm | 2489.24 mm ³ | 38.55 ms (36.20, 42.36) | 31.00 ms (30.62, 31.38) | |
| | Combined | 2.36 mm | 4262.30 mm ³ | 38.49 ms (36.67, 42.10) | 31.82 ms (31.35, 32.29) | |

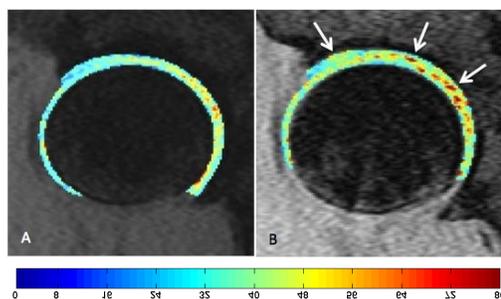


Figure 2. Sagittal views of the femoral head and acetabulum (the anterosuperior region is up and to the left). (A) The $T_{1\rho}$ color map of a control overlaid on the first echo (TSL = 0 ms) of the $T_{1\rho}$ mapping sequence. (B) The $T_{1\rho}$ color map of an FAI patient. The arrows indicate focal differences in relaxation times between the patient and control. (Color scale is in milliseconds).

Discussion

Our study demonstrates a high level of reproducibility for measurements of hip cartilage thickness, volume, $T_{1\rho}$ and T_2 relaxation times, and alpha angle with CV_{RMS} values less than 5%, consistent with our prior studies (1). The mean $T_{1\rho}$ and T_2 values of the cartilage ROIs could have masked regional variations in the relaxation times, and in the future we aim to examine these regional differences by further subdividing the hip cartilage ROIs. While this study was limited by the number of subjects, it establishes the reproducibility and documents the feasibility of using MRI techniques to monitor the health of articular hip cartilage in patients with OA.

Acknowledgements

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References

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