Effect of knee joint positioning on the reproducibility of T2 relaxation time of articular cartilage in vivo

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INTRODUCTION

Measures of knee hyaline cartilage quantity from MR have been shown to be useful biomarkers for Osteoarthritis disease understanding and drug development [1] but measures of cartilage quality could potentially provide earlier indicators of the disease process, prior to cartilage degeneration. T2 relaxation time in hyaline cartilage is dependent on the integrity of the collagen network and the orientation of collagen fibrils i.e. the magic angle effect [2]. In in-vivo measurements, unavoidable variation in joint positioning between repeated image acquisitions alters the angle between the collagen fibrils and magnet B0 which has a detrimental effect on the reproducibility of T2 measurements. The objective was to determine the variation in the orientation of the collagen fibrils, with respect to B0, between successive scans and its effect on measures T2 relaxation within sub-regions of the knee joint.

MATERIALS AND METHODS

The right knees of three asymptomatic male volunteers (age 30-33 years, normal weight) were each imaged five times at 1.5 T using a clinical scanner (GE Signa HDx, GE healthcare, Milwaukee, WI, USA) within three weeks. The flexion angle and rotation of the knee was controlled by stabilizing the ankle to a fixed position with a leg holder and by using a custom-made inflatable cushion to fix the joint within the knee coil. T2-weighted images were acquired in the sagittal plane using a multi-slice spin echo sequence (TR=1000 ms, TE=10ms, 3-mm slice thickness FOV=12 cm, matrix size 256*256 yielding 0.51 mm in-plane resolution).

Automatic segmentation of the distal femur bone was performed by an Active Appearance Model (AAM) [3] which provided a set of 4098 anatomically corresponded points on the bone surfaces in each study image. The direction of the deep cartilage collagen fibrils was approximated as the 3D normal to the bone surface. The angle between the 3D bone surface normals and B0 field was calculated at each corresponding point on all images.. The dense anatomical correspondence, provided by the AAM, enabled calculation of the variation in angle at each point over all five scans for each volunteer. The effect of positioning inaccuracy on absolute T2 values was simulated by utilizing previously acquired in vitro data on the orientational dependence of T2 in different cartilage laminae at 7T (Fig. 1) [2]. Finally the mean angle, angular variation (variance) and corresponding T2 values were determined for anterior weight-bearing (AWB) and posterior weight-bearing (PWB) regions of interest (ROI) for each condyle and superficial, intermediate and deep cartilage (Fig. 2).

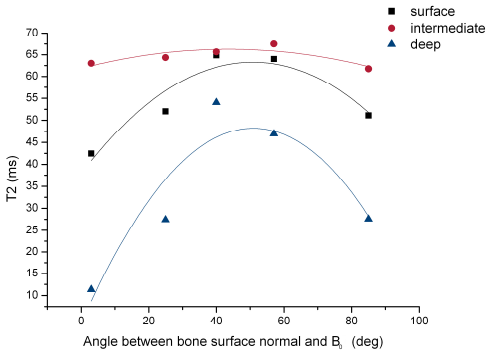

Figure 1: Dependence between T2 and orientation to B0 at different cartilage laminae.

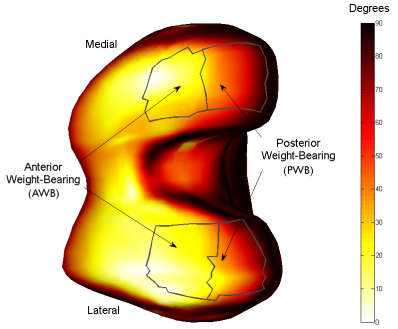

Figure 2: Angle between B0 and bone surface normal, in degrees, averaged over five acquisitions for the first patient on the study illustrated on the bone model's mean shape. Also shown are the joint sub-regions within which the variation in angle and reproducibility of T2 measures were analysed.

RESULTS

Considerable variation in joint angle was observed in both inter- and intra-subject assessment (Table 1). Highest angular variation with respect to B0 was observed at lateral PWB with inter-subject difference of 10.1º around a mean of 43.2º. The predicted effect on T2 value, however, was no more than 2.5ms since the effect of angular alteration on T2 relaxation time is dependent on the angle relative to B0, i.e. the magic angle effect. In medial AWB, where the mean angle to B0 was smaller, the mean angle difference of 3.8º caused a variation of 4.2ms on the predicted T2 value. The highest expected intra-subject variation due to joint positioning was observed for patient 2 at lateral AWB (4.7ms). For most subjects and ROIs the expected variation in T2 due to positioning error of the joint was typically <1ms. The T2 variation due to joint positioning was strongest in the deep cartilage, followed by the superficial tissue. The T2 variation was smallest (≤0.1ms) in intermediate cartilage.

DISCUSSION

In the presented study, careful joint positioning protocol resulted in small mean angular variation in the range of 0.2-8.0º for different subjects and ROIs. According to simulations, this translates to a maximum expected T2 variation of 4.7ms, however, for most regions the variation was <1ms. Reproducibility of cartilage T2 in vivo was better than reported in a previous study [4]. In the present study, the effect of altering the joint position on T2 measures differed considerably between different cartilage zones. In the clinical setup, the most superficial cartilage was not visible due to reduced image resolution.

The sole effect of orientation on cartilage T2 has not been previously determined in different collagen zones in vivo. Considering the degree of T2 differences between normal and degenerated cartilage [5] the present results demonstrate that with careful joint positioning the error in T2 due to joint positioning is acceptable.

REFERENCES

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Table 1: Effect of varying orientation on T2 at different joint surfaces for three volunteers (vol1-vol3) at five repeated measurements

Region		Mean angle to B0 (deg)			Mean angular variation (deg)			T2 (ms)			Variation in T2 (ms)		
		vol1	vol2	vol3	vol1	vol2	vol3	vol1	vol2	vol3	vol1	vol2	vol3
Lateral AWB	surface							50.3	50.0	50.1	0.9	1.5	0.1
	intermediate	14.5	14.1	14.1	1.7	3.0	0.2	64.3	64.2	64.2	0.1	0.1	<0.1
	deep							25.3	24.8	24.9	2.7	4.7	0.4
Lateral PWB	surface							63.2	61.8	62.5	<0.1	0.1	0.1
	intermediate	48.8	38.7	42.1	4.5	1.8	4.2	66.2	66.2	66.3	<0.1	<0.1	<0.1
	deep							48.1	45.6	46.8	<0.1	0.3	0.3
Medial AWB	surface							54.4	52.0	53.7	0.1	0.2	0.2
	intermediate	20.7	16.9	19.6	0.2	0.6	0.5	65.1	64.6	64.9	<0.1	<0.1	<0.1
	deep							32.5	28.3	31.3	0.2	0.7	0.6
Medial PWB	surface							63.0	63.2	62.8	<0.1	<0.1	<0.1
	intermediate	55.2	49.7	57.6	8.0	0.9	1.3	65.9	66.2	65.8	<0.1	<0.1	<0.1
	deep							47.8	48.2	47.4	0.1	<0.1	<0.1