T2 relaxation time of human articular cartilage at 1.5T and 9.4T: correlation with tissue mechanical properties

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INTRODUCTION

Articular cartilage constituents, i.e. proteoglycans, the three-dimensional collagen network and interstitial water, and their interactions have a major role in the loading response of cartilage [1]. T2 mapping of cartilage has been reported to be sensitive to the constituents, particularly collagen. T2 has formerly been correlated with the biomechanical properties of animal cartilage [2-5] and human cartilage at 9.4T [6], however, these relationships have not been studied by using a clinical MRI system with clinically feasible imaging parameters. To address this issue, the inter-relationships between the mechanical properties and T2 relaxation time of human articular cartilage both at 1.5T and 9.4T field strengths were investigated.

METHODS

Patellae of human cadavers (N=14, 12 male, 2 female, age 55 ± 18 years) were equilibrated overnight in 0.5mM Gd-DTPA(2-) solution. It has been shown that at low contrast agent concentrations the T2 relaxation time of cartilage is not significantly affected by Gd-DTPA(2-) [7]. For 1.5T MRI measurements (GE Signa 1.5T magnet, GE Healthcare, Milwaukee, WI), the articular surface of intact patellae were oriented parallel to B0 to emulate clinical patient positioning. Six topographical locations were assessed: superolateral (SL), superomedial (SM), central lateral (CL), central medial (CM), inferolateral (IL) and inferomedial (IM). T2 maps were calculated from multi-slice multi-echo spin echo experiments (GE prototype sequence, TR=1000ms, TE=10.3-82.4ms, ETL=8, 3-mm slice thickness, 0.313mm in-plane resolution at room temperature, duration 7 min). Subsequently, full-thickness cartilage disks (dia. = 4 mm) without subchondral bone were prepared from marked locations. At 9.4T (Oxford 400 NMR vertical magnet, Oxford Instruments Plc, Witney, UK, and SMIS console, SMIS Ltd., Surrey, UK), T2 was determined from six single spin echo measurements (TR=1500ms, TE=14-80ms, 1-mm slice thickness, 0.039mm resolution across cartilage depth, at 25±1 °C, duration 58 min) with the cartilage surface perpendicular to the B0 field. The 9.4T data were downsampled to match the resolution of the 1.5T data. Superficial T2 values from the first 0.938mm (corresponding to 3 and 24 pixels for 1.5T and 9.4T experiments, respectively) were averaged to characterize the more superficial tissue. Bulk T2 values were calculated by averaging the pixels in each profile.

Prior to biomechanical testing the cartilage disks were re-equilibrated in phosphate buffered saline solution for at least two hours to wash-out the contrast agent. Stress-relaxation tests were conducted in unconfined geometry with a 10% pre-strain and three 2% steps with relaxation time of 30min to determine the Young's modulus from the equilibrium response [8].

RESULTS

Depth-wise T2 profiles showed a similar shape at 1.5T and 9.4T, with long T2 values in the more superficial tissue and short T2 values in deeper cartilage (Fig. 1). Superficial T2 values varied between 29 and 105 ms (mean 63 ± 1ms) and between 22 and 62 ms (40 ± 9 ms) at 1.5T and 9.4 T, respectively. Bulk T2 values varied between 32 and 116 ms (51 ± 15 ms) and between 17 and 50 ms (28 ± 7ms) at 1.5T and 9.4T, respectively. T2 at 1.5T and 9.4T were linearly correlated by r = 0.41 ($p<0.01$) and r = 0.41 ($p<0.01$) for superficial and bulk tissue, respectively. The topographical variation of superficial R2 (i.e. 1/T2) and Young's modulus revealed a similar trend both at 1.5T and 9.4T (Fig. 2). A moderate linear correlation between the superficial T2 values and Young's moduli was observed, r = -0.55 and -0.37 at 1.5 and 9.4T, respectively ($p<0.01$, N=14). Bulk T2 values and Young's moduli were linearly correlated by r = -0.42 at 1.5T and r = -0.43 at 9.4T ($p<0.01$).

DISCUSSION

The current results demonstrate the feasibility of T2 mapping to reflect the biomechanical properties of articular cartilage, both at 1.5T and 9.4T. The topographical variation of T2 at both field strengths was similar to that of Young's modulus, and the linear correlations between T2 and Young's modulus were significant for 1.5T and 9.4T. The present results also suggest that the T2 relaxation time measurements are indicative of the mechanical integrity of cartilage in the presence of Gd-DTPA(2-).

A significant difference in T2 between the two field strengths was observed. This is anticipated to relate to the different sample orientation (i.e. collagen arrangement), known to have a significant effect on T2 relaxation time through dipolar interaction [9]. Despite the different sample orientation and field strength, a significant relationship between T2 and mechanical properties is observed.

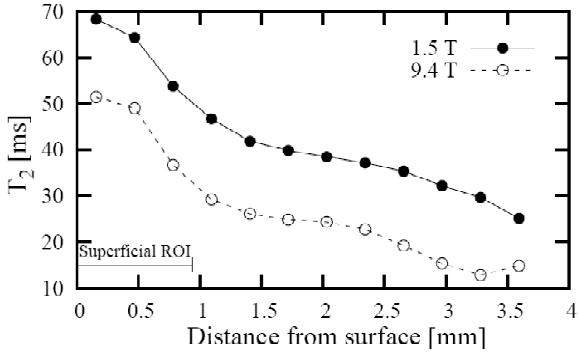

Fig. 1: Depth-wise profiles of T2 relaxation time at 1.5T and 9.4T in a representative sample. The 9.4T data has been downsampled to match the resolution of the 1.5T profile. The orientation of sample surface was parallel to B0 field for 1.5T measurements and perpendicular to B0 field for 9.4T measurements.

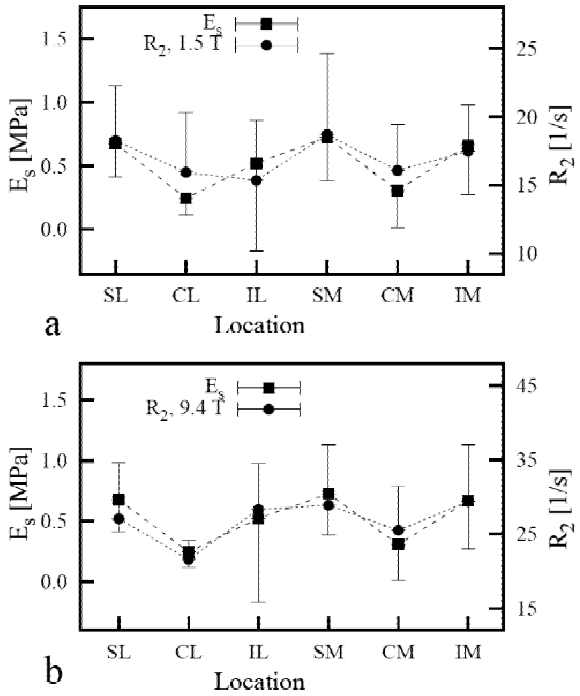

Fig. 2: Topographical variation of Young's modulus E_s and R2 (1/T2) at different topographical locations (mean ±SD) at cartilage surface (first 0.938mm) for 1.5T (a) and 9.4T (b).

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