Spatial Relaxivity of Gadolinium Complexes in Articular Cartilage

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INTRODUCTION

Delayed Gadolinium Enhanced MRI of Cartilage (dGEMRIC) is a technique for non-destructive estimation of cartilage fixed charge density, produced mainly by the proteoglycan macromolecules (1,2). While the feasibility of the technique has been shown in several studies, the possible variation of T1 relaxivity with cartilage degeneration (change in macromolecular content) may provide a source of uncertainty (3,4). Theoretically, this uncertainty is also related to normal cartilage since the macromolecular content of cartilage is known to vary with tissue depth. To address this issue, the depth-wise relaxivity of non-ionic Gd-HPDO3A was determined by assuming an equal concentration in tissue and in the equilibrating solution (5). The effect of spatially varying relaxivity on the dGEMRIC technique was investigated by assuming equal relaxivities for Gd-HPDO3A and Gd-DTPA(2-) (5).

MATERIALS AND METHODS

Bovine knee joints were obtained from the local abattoir and 4-mm cartilage discs without subchondral bone (n = 3) were prepared from the lateroproximal patellae and immersed in phosphate buffered saline (PBS) containing enzyme inhibitors for two hours prior to MRI measurements. T1 relaxation time of the specimen in PBS was measured at 9.4 T using a saturation recovery spin echo sequence (TE = 14 ms, 6 TRs 200 - 5000 ms, 39μm pixel size across cartilage thickness). Subsequently, the T1 relaxation time was determined (TE = 14 ms, 6 TRs 100 – 1500 ms) after equilibration (minimum of 2.5h) of the samples in 1.0 mM Gd-DTPA(2-) (dGEMRIC experiment), and 0.25, 0.5 and 1.0 mM Gd-HPDO3A, and finally again in 1.0 mM Gd-DTPA(2-) to verify that the tissue samples remained unaffected throughout the equilibration procedures.

Depth-wise relaxation time profiles were determined and, consequently, depth-wise T1 relaxivity (R) profiles were calculated by fitting the T1 data at various Gd-HPDO3A concentrations into the equation $[Gd] = R^{-1}(T_{1Gd}^{-1} - T_1^{-1})$, assuming that the concentration of Gd-HPDO3A in the tissue and equilibrating solution was the same (5). Finally, the spatial relaxivity information was applied to calculate the Gd-DTPA(2-) concentration ([Gd-DTPA(2-)]) in tissue, and this was compared with the [Gd-DTPA(2-)] as calculated using a single, constant relaxivity value (mean from all samples).

RESULTS

T1 relaxation time of cartilage without the contrast agent ranged between 1580 and 2350ms (2030 ± 220ms, mean ± SD). The T1 relaxation time in the presence of Gd-HPDO3A was significantly shorter as compared to the T1 in the presence of Gd-DTPA(2-), indicative of the different accumulation of the non-ionic and ionic contrast agents. Among the three samples the relaxivity of Gd-HPDO3A varied between 2.82 and 3.44 $(mM*s)^{-1}$, with the mean relaxivity value of 3.21 $(mM*s)^{-1}$ (Fig. 1). Using the mean relaxivity value in [Gd-DTPA(2-)] calculations resulted in an error of -0.1 ± 4.1% (mean ± SD), as compared to [Gd-DTPA(2-)] determined using the spatial relaxivity information (spatial T1,0 values were used in both calculations) (Fig. 2). Calculating [Gd-DTPA(2-)] by using the spatial relaxivity information and the mean T1,0 value instead of spatial T1,0 resulted in an error of -0.9 ± 5.0% (mean ± SD), (data not shown). The mean difference between the first and last dGEMRIC experiment was 2.8 ± 4.9%.

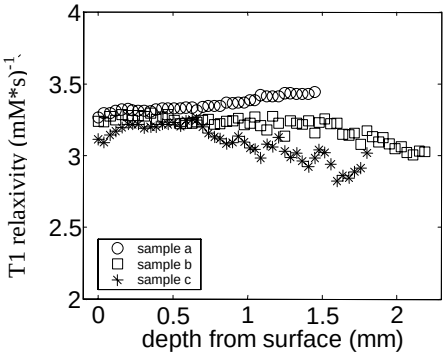

Fig. 1: Relaxivity of Gd-HPDO3A as a function of cartilage depth in three bovine cartilage samples.

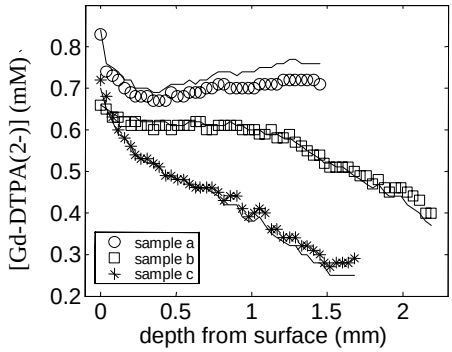

Fig. 2: Depth-wise contrast agent concentrations for three samples as determined by using the mean relaxivity value (solid line) and spatial relaxivity information (symbols).

DISCUSSION

Our results indicated that the depth-wise variation in T1 relaxivity of gadolinium complexes is small and had only a minor effect on the calculated contrast agent concentration of the dGEMRIC experiment. A small difference in the bulk relaxivities of Gd-DTPA(2-) and Gd-HPDO3A has been reported for cartilage (5), however, this model serves as a good estimate for the effect of variation in relaxivity for Gd-DTPA(2-) and its effect on dGEMRIC (i.e. [Gd-DTPA(2-)] calculations). The variation of relaxivity with macromolecular content is more pronounced at lower field strengths (3,5), and therefore studies at lower field strengths are necessary. The effect of T1,0 on [Gd-DTPA(2-)] calculations is only minor, despite of its considerable variation across the cartilage depth.

REFERENCES

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