T1ρ and T2 of fat and water as surrogate markers for trabecular bone structure

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INTRODUCTION

Trabecular bone is a biphasic structure formed by fluid-like bone marrow and a three-dimensional lattice of trabecular plates. Previously, T_2* relaxation time has been shown to be sensitive to local inhomogeneities in magnetic fields induced by discontinuities of magnetic susceptibility at the surface of the trabeculae, [1] serving as a surrogate marker for bone mineral density and mechanical properties of trabecular bone [2]. Binarized MR images with sufficient resolution have also been used for the evaluation of trabecular structure [3]. As an alternative to the imaging approaches, magnetic resonance spectroscopy (MRS) techniques could be applied for more detailed assessment of relaxation properties of different constituents of bone marrow. In the present study, we investigated the feasibility of $T_{1\rho}$ dispersion and T_2 of fat and water to serve as surrogate markers for trabecular bone structure.

METHODS

Bovine knee joints (N=5) were obtained from the local slaughterhouse. Three cylindrical osteochondral plugs (dia.=22 mm) were isolated from selected locations of each knee: medial femoral condyle, medial tibial plateau and lateral facet of the patella. MRS measurements were conducted using a 4.7 T Magnex horizontal magnet and Varian ^{UNITY}INOVA console. To determine $T_{1\rho}$ relaxation time spectra were measured using the LASER pulse sequence [4] (TR=4 s, TE=23 ms, 5*5*5mm^3 voxel size) with spin-lock preparation block consisting of adiabatic half passage (AHP), variable length spin-lock period and reverse AHP [5]. Seven spin-lock times (19.5-79.5 ms) were used at ten different B_1 field strengths (0.18-1.8 G) to determine the dispersion of $T_{1\rho}$. T_2 relaxation time was measured using the same pulse sequence with double spin-echo preparation block consisting of AHP, two adiabatic full passages and reverse AHP. Signal intensities were determined from resulting spectra separately for fat and water and corresponding $T_{1\rho}$ and T_2 values were fitted to monoexponential relaxation formulae.

MicroCT measurements (Skyscan 1172, Skyscan, Belgium, voxel size 21µm) were conducted to obtain accurate information of trabecular structure. Bone volume fraction (BV/TV), trabecular thickness (Tb.Th) and trabecular separation (Tb.Sp) were calculated with CTAN software provided by the manufacturer.

RESULTS

T1ρ relaxation times of fat and water showed a different behavior as a function of B_1 field strength (Fig. 1). The variation and standard deviation of $T_{1\rho}$ values were higher for water than for fat. The mean $T_{1\rho,w}$ value for all samples also increased more as a function of B_1 field than $T_{1\rho,f}$. The linear correlations between structural properties and $T_{1\rho,f}$ at different B_1 field strengths varied remarkably (Figures 2c and 2d). The correlation coefficient between $T_{1\rho,w}$ and structural properties were almost constant for all B_1 values. The mean T_2 relaxation time for all samples was 61.2±4.1 for fat ($T_{2,f}$) and 40.0±6.5 ms for water ($T_{2,w}$). $T_{2,f}$ and $T_{2,w}$ correlated significantly with BV/TV (r = 0.75 and 0.76, respectively, $p < 0.01$) and Tb.Th (r = 0.77 and 0.74, respectively, $p < 0.01$). The mean values for BV/TV, Tb.Th and Tb.Sp were 33.7±6.4 %, 228±44 µm and 918±40 µm, respectively.

DISCUSSION

We have presented preliminary experimental results for applying quantitative spectroscopic methods for trabecular bone. $T_{1\rho}$ and T_2 relaxation time show a considerable dependence on the structural properties of bone. We assume that $T_{1\rho}$ relaxation is influenced by diffusion of molecules in the presence of strong local field gradients at the bone-lipid/water interface. The contribution of this is evidently dependent on B_1 and diffusion. Diffusion of water has been determined to be in order of magnitude higher than that of fat, explaining the different sensitivity of $T_{1\rho,f}$ and $T_{1\rho,w}$ to bone structure parameters. By determining quantitative properties for fat and water components of bone marrow separately and applying a theoretical model for $T_{1\rho}$ relaxation, it may be possible to obtain accurate information of trabecular structure and even predict the mechanical strength of trabecular bone.

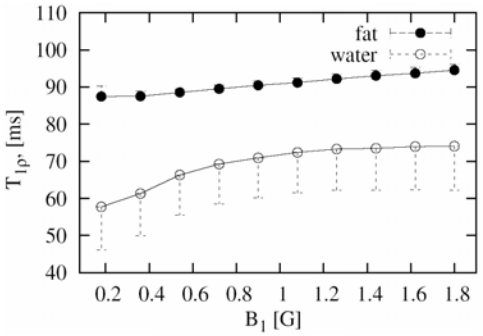

Figure 1. The dispersion of $T_{1\rho}$ relaxation time as a function of B_1 field for fat and water.

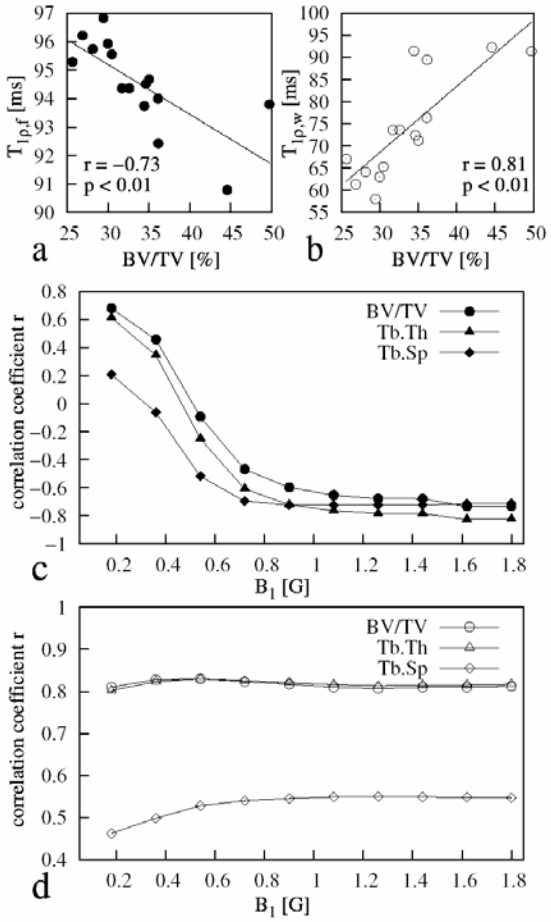

Figure 2. Scatter plot of T1ρ relaxation time versus bone volume fraction at B1 value 1.8G for a) fat and b) water and the variation of correlation coefficients between T1r relaxation time of fat and bone volume fraction (BV/TV), trabecular thickness (Tb.Th) and trabecular separation (Tb.Sp) as functions of B1 field for c) fat and d) water.

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