Orientation anisotropy of rotating frame and T_2 relaxation parameters in articular cartilage

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Introduction

Previous reports have indicated an orientation dependency for T_2 relaxation time constant in articular cartilage (1). The sensitivity of T_2 to the collagen fibril network has been demonstrated and ascribed to the residual dipolar coupling (1). Furthermore, orientation sensitivity in articular cartilage has been demonstrated for continuous-wave (CW) $T_{1\rho}$ (2). Rotating frame relaxation (RFR) methods including adiabatic $T_{1\rho}$, adiabatic $T_{2\rho}$ and Relaxation Along a Fictitious Field (RAFF) have been recently proposed for quantitative assessment of articular cartilage (3,4). The purpose of the present study was to investigate the orientation dependency of several of RFR parameters in articular cartilage.

Methods

A cylindrical osteochondral plug from bovine lateroproximal patella was carefully prepared to ascertain that the sides were cut exactly perpendicular to the articular surface. The sample was placed inside a custom-built PTFE rotation holder, immersed in perfluoropolyether (Fomblin® LC08, Solvay Solexis, Milan, Italy). MRI was performed at 9.4 T (Oxford instruments Plc, Witney, UK) with a 19 mm quadrature RF volume transceiver (RAPID Biomedical GmbH, Rimpar, Germany) and Varian DirectDrive console VnmrJ2.3 (Varian Inc. Palo Alto, CA, USA). Initially the sample was oriented with surface normal parallel to $\boldsymbol{B}_0$. The sample was imaged at seven different orientations of the surface normal with respect to $\boldsymbol{B}_0$; scout images were obtained every time and the orientation of the sample was confirmed and measured from the scouts. $\boldsymbol{B}_0$ shimming and RF power calibration were also repeated for each orientation. For the relaxation time measurements, a global preparation block coupled to fast spin echo (FSE) readout was used (TR=5s, ESP=5ms, ETL=4, matrix=256x64, FOV=16x16mm, 1mm slice, resolution along cartilage depth 62.5µm). In particular, T_2 relaxation was measured using adiabatic double spin echo (DSE) and CPMG preparation blocks, CW-$T_{1\rho}$ was measured with spin-lock-pulse (γB_1=650Hz) embedded between adiabatic half passages, adiabatic $T_{1\rho}$ with a train of HS1 pulses (τ_p= 4.5ms, BW=2.2kHz and $\gamma B_{1,max}$= 2.5kHz), and adiabatic $T_{2\rho}$ with similar train embedded between adiabatic half passages. T_{RAFF} (3) was measured using a train of sine/cosine modulated pulses for one orientation of the fictitious field ε=45° with pulse power γB_1=625Hz. All measurements were repeated at every orientation.

Results

The orientations between cartilage surface normal and $\boldsymbol{B}_0$, as measured from the scout images were 4, 14, 33, 48, 56, 73 and 90 degrees. T_2 relaxation time, as measured by both adiabatic DSE and CPMG pulse train demonstrated strong orientation dependence (Figure 1). T_{RAFF}, as well as adiabatic $T_{2\rho}$ had an orientation dependence closely matching to that of T_2. The orientation dependence of CW-$T_{1\rho}$ had features similar to T_2 (i.e., relaxation time increasing throughout the tissue and becoming more homogenous at around magic angle), but showed markedly less depth-wise dependence. Adiabatic $T_{1\rho}$ had largely reduced dependence on the sample orientation.

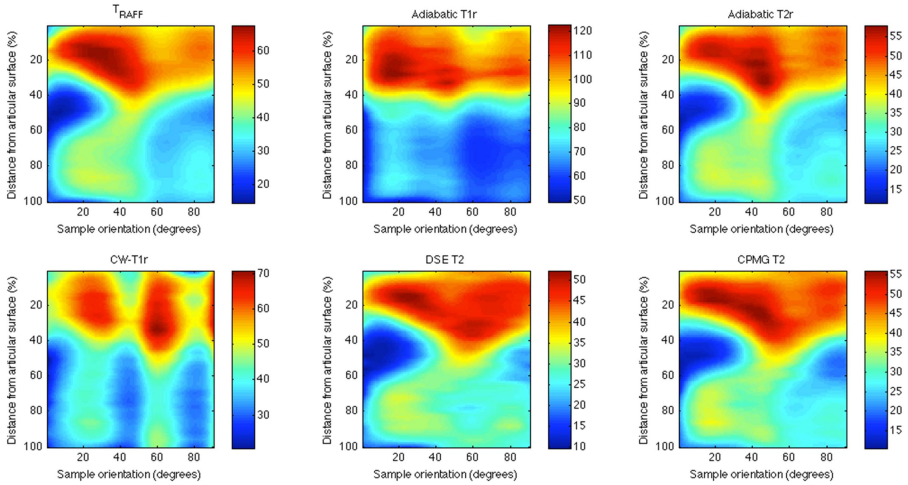

Figure 1. Orientation dependence of the different relaxation time constants (ms). In each case, the time constants have been scaled independently (linearly) for equal visual appearance.

Discussion and conclusions

Orientation dependence of various RFR parameters and T_2 within the range 0-90-degrees in articular cartilage was investigated. The depth-wise dependence of T_2 relaxation time was confirmed and demonstrated as reported previously (1). Orientation dependence of CW-$T_{1\rho}$ has also been previously reported, and the results of the present study are in agreement with the previous reports using approximately same spin-lock power (500Hz vs. 650Hz in the present study) (2). The orientation dependencies of adiabatic $T_{1\rho}$, adiabatic $T_{2\rho}$ and T_{RAFF} have not been previously reported for articular cartilage. The present results indicate a dependence of T_{RAFF} and adiabatic $T_{2\rho}$ very similar to T_2. On the other hand, adiabatic $T_{1\rho}$ was observed to be much less dependent on orientation, indicating that adiabatic $T_{1\rho}$ is less sensitive to the magic angle effect in cartilage (5). A reduced orientation dependence with increase of spin-lock power has been demonstrated for CW-$T_{1\rho}$ (2); however, this approach leads to increased RF power deposition, thus challenging clinical implementation. For T_2 relaxation time constant, the clinical use has been confounded by the fact that it significantly depends on the orientation of the cartilage tissue with respect to the main magnetic field, since the natural curvature of most of the joints covers well over 90 degree range. The present results indicate that adiabatic $T_{1\rho}$ is not influenced by this confounding factor and promote its use as an orientation-independent biomarker for the assessment of articular cartilage. RAFF method with smaller angles of the fictitious field in the ω_{eff} frame (6) could also provide insensitivity to orientation dependence of the relaxation parameters combined with significantly reduced specific absorption rate (SAR). However, this is a subject of future studies.

References

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