A multi-component analysis of T_1/T_2 relaxation of bovine articular cartilage in low fields

Oleg V. Petrov, Siegfried Stapf

FG Technische Physik II/Polymerphysik, Technische Universität Ilmenau, D-98684 Ilmenau, Germany

Articular cartilage is a thin layer of connective tissue that covers and protects the articular surfaces of bones. It consists mainly of collagen (15–20% w.w.), proteoglycants (3–10% w.w.), and water (65–75% w.w.). Structurally, articular cartilage is subdivided into four distinct parallel zones based on the local orientation of collagen fibrils.

Degeneration of articular cartilage results in osteoarthritis, one of the main causes of chronic disability among elderly. A number of MRI techniques used for the early detection of osteoarthritis rely on spatially resolved measurement of T_1, T_2, and $T_{1\rho}$ relaxation times, as they have shown correlation with the cartilage composition and structure [1]. To complement the MRI biomarkers, variable-field measurements of T_1 have been carried out with field-cycling (FC) relaxometers in the frequency range of 0.01–40 MHz ^{1}H, which includes the region of quadrupolar peaks (q-peaks). A statistically significant difference between osteoarthritic and healthy cartilage samples has been revealed for both the magnitude of the q-peaks and position of the entire T_1-dispersion profile [1]. These findings, among results obtained for other biological samples, underlie the concepts of field-cycling imaging [2].

Seeking to add to this methodology, we explore non-exponentiality of T_1/T_2 relaxation in articular cartilage which can be anticipated, in particular, from its zonal structure. Indeed, slice selective T_1 measurements on bovine articular cartilage with NMR-MOUSE have revealed a considerable variation in T_1 from one zone to the other [3]. Here we report on T_1 relaxation broadening as a function of magnetic field strength, B_{rlx}, measured in terms of the geometric standard deviation (GSD) of T_1. The GSD is calculated from a logarithmic moment analysis of relaxation functions without data inversion [4]. It was found that the GSD of T_1 in articular cartilage significantly exceeds unity (mono-exponential case) in all B_{rlx} interval covered in a FC experiment (3 kHz to 25 MHz) and it has the global maximum at B_{rlx} = 0.55–0.65 MHz. Inverse Laplace Transform (ILT) of the data shows a unimodal T_1 distribution with a long tail toward short T_1 value (Fig. 1). For comparison, it is not observed, or at least much less pronounced, in bovine meniscus tissue which is made entirely of fibrocartilage.

To complement the field-cycling T_1 measurements, we carried out conventional T_1/T_2 relaxometry of both articular cartilage and meniscus tissue at 43 MHz. At this frequency the T_1 distribution by ILT collapses to a single peak, thus indicating a mono-exponential T_1 relaxation, whereas a T_2 distribution shows two distinct peaks with intensities 17:3, the major component (presumably water) having $T_1/T_2 \approx 10$.

We have also explored multi-component relaxation in bovine cartilage through decomposition of T_1 dispersion profiles, as obtained in the FC experiment, into a sum of Lorentzian components (Fig. 2). This approach allows, in principle, to differentiate relaxation components that are undistinguishable on both T_1 and T_2 time scales due to magnetization exchange.

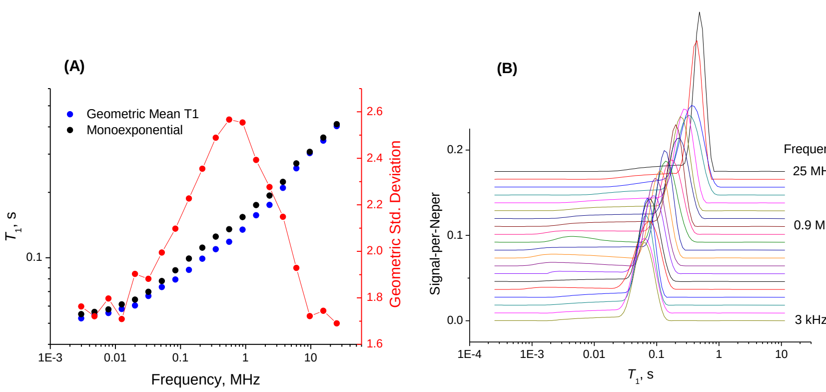

Fig. 1. (A) T_1 dispersion profile (scatter) and GSD of T_1 (line+symbol) in bovine articular cartilage. (B) T_1 relaxation time distributions.

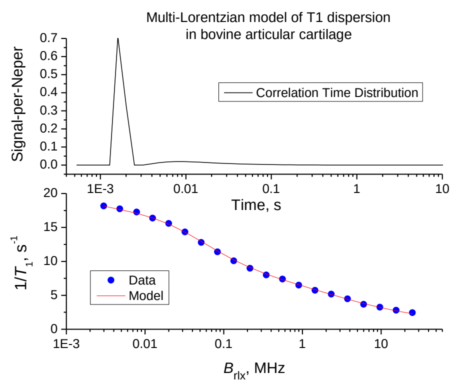

Fig. 2. Multi-Lorentzian analysis of T_1 dispersion profile of bovine articular cartilage.

References

[1] Biophysics and Biochemistry of Cartilage by NMR and MRI. Edited by Y. Xia and K. Momot, The Royal Society of Chemistry 2017

[2] The European Union's Horizon 2020 research and innovation programme under grant agreement No 668119 (project "IDentiFY")

[3] Eriks' paper

[4] O. V. Petrov and S. Stapf, Parameterization of NMR relaxation curves in terms of logarithmic moments of the relaxation time distribution, *J. Magn. Reson.* **279** (2017) 29-38.