Bovine and human cartilage studied by low-field and variable-field NMR relaxometry: correlations for pre-clinical and clinical investigations

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The layered structure of mammalian articular cartilage, which is a consequence of different degrees of order of the collagen fibers but also of a gradient of water and glycosaminoglycan (GAG) concentration, results in a pronounced T_2 variation at all magnetic field strengths [1]. A similar variation of T_1, typically covering a ratio of 3-5 between maximum and minimum values inside the tissue, was identified at a field strength of 0.27 T employing the NMR-MOUSE, while it has been reported as minimal at high magnetic field strengths [2]. T_1 thus has been identified as a suitable parameter to follow changes in cartilage properties by low-field NMR. While previously the T_1 relaxation rate at 400 MHz has been associated with water content of articular cartilage [3], T_1 at lower field strength is anticipated to relate more directly to cartilage constituents.

Average T_1, as well as cartilage thickness obtained from T_1 measurements of human samples, is found to correlate negatively with the degree of osteoarthritis in humans [4,5]. At the same time, a significant correlation was identified for relaxation time reduction before and after uniaxial compression at 0.6 MPa, a typical value for forces appearing in the human knee and hip joint. This finding is of importance since the spatial resolution of 50 μm obtained with the single-sided scanner is about one order of magnitude better than the one in clinical high-field or low-field scanners [6], thus allowing a much more reliable definition of thickness change which even includes resolution of the three main cartilage layers.

At ^{1}H Larmor frequencies of 2-3 MHz, the so-called quadrupolar dips are superimposed onto a frequency-dependent signature of T_1 that can be approximated by power-laws. Varying the composition, water content or structural integrity of cartilage affects both the general frequency dependence of T_1 and the shape of the quadrupolar dips, providing a possible diagnostic access to arthropathies such as osteoarthritis (OA) [7]. In this study, a statistically significant correlation of the area of the quadrupolar dips with osteoarthritis is demonstrated: diseased tissue contains less GAG but more water. This observation is confirmed by artificially altered tissue using trypsin or collagenase [8]. Furthermore, the power-law exponent of the frequency dependence of T_1 correlates with the thickness of the tissue, providing a further approach to relating the molecular mobility to the macroscopic properties of cartilage. These results allow for an improved diagnostic interpretation of low-resolution clinical MRI particularly at dedicated extremity scanners. Finally, a recent study shows that the maximum width of the T_1 distribution in bovine cartilage appears at an intermediate field strength of about 20 mT, suggesting a suitable parameter such as the value of the logarithmic moments of distribution [9] as a promising biomarker for in-vivo studies.

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