Detection of osteoarthritic changes in cartilage by FFC NMR

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Introduction

Conventional MRI is performed at a fixed, high magnetic field in order to obtain high signal-to-noise ratio and high resolution. However, proton MRI at such magnetic strengths is known to give results related mostly to free water, hence providing little information about water-protein interactions. One way to solve this issue is to change the main magnetic field during the NMR experiment and collect information at a range of fields: this is the principle of fast field-cycling MRI (FFC-MRI).

In this work, we are investigating the use of the ^{1}H-^{14}N quadrupolar cross-relaxation process, which occurs when a sufficiently immobilised NH entity is in contact with low-mobility water molecules [1]. Under such conditions, a field-dependant magnetisation transfer occurs between the bulk water and the ^{14}N nuclei, which acts as a sink of magnetisation at certain specific field strengths. This generates bell-like features in the dispersion curve (R_1 versus magnetic field), called 'quadrupolar peaks', at well-defined field strengths where the ^{14}N nuclear quadrupole resonance and ^{1}H NMR frequencies coincide (typically 16, 49 and 65 mT).

This preliminary study makes use of the properties of the ^{14}N quadrupolar relaxation process to detect changes in samples of healthy or osteoarthritic cartilages, using a field-cycled NMR relaxometer.

Methods

The cartilage samples were obtained from hip replacement surgery. The population consisted of 11 patients (32 samples) with osteoarthritic cartilage and 9 patients (23 samples) with healthy cartilage operated for fractured neck of femur. All data were processed anonymously.

The samples were analysed with a SMARTracer field-cycled relaxometer (Stelar S.r.l., Italy) one day after surgery, using an inversion-recovery T_1 measurement sequence at several fields from 0.4 to 5 MHz ^{1}H at 37°C. A denser sampling was performed in the region of the quadrupolar signal, between 0.4 and 0.9 MHz ^{1}H and between 1.5 and 3.5 MHz ^{1}H (Fig. 1). The results were analysed with a least-square curve fitting algorithm (Matlab) using a model derived from the literature [2] that fitted the data using Lorentzian bells for the peaks and a power law for the background signal.

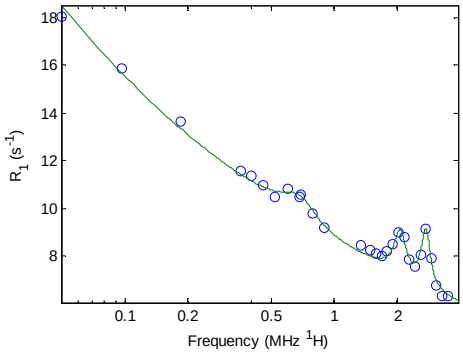

Figure 1: Dispersion curve obtained from a diseased cartilage. The quadrupolar peaks appear at 0.6, 2.0 and 3.0 MHz app.

Results

The quadrupolar peaks were clearly observed in the dispersion curve. Both the level of the background line (c_1 parameter, Fig. 2) and the quadrupolar peak amplitude (ΔR_1, Fig. 3) showed significant decreases on going from normal to diseased samples of cartilage. The error bars in the figures stand for the 1-sigma interval. The average decrease ratio measured between healthy and diseased cartilage samples were 0.74±0.05 and 0.60±0.27 for the c_1 and ΔR_1 parameters respectively, which corresponds with the literature [3].

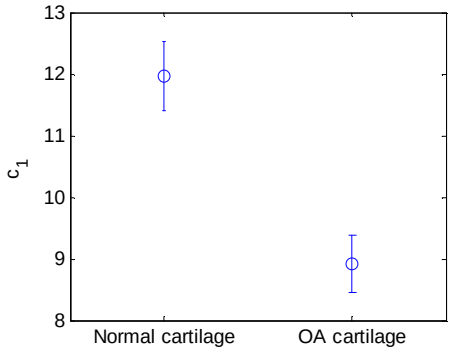

Figure 2: Vertical shift of the background line (p-value = 2.0x10^{-10}).

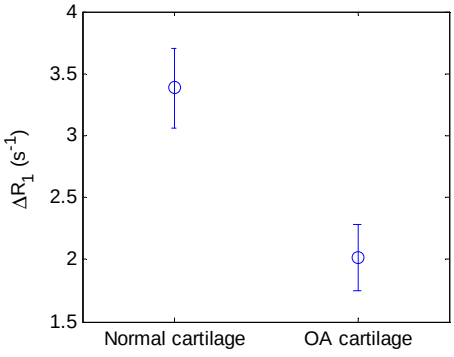

Figure 3: Normalised amplitude of the quadrupolar peaks (p-value = 4.1x10^{-9}).

Conclusions

The amplitude of the quadrupolar peak is known to be linearly dependant on the protein concentration [1, 2], so the results obtained show a decrease of the protein concentration in diseased cartilage. The data cannot show if this is due to a decrease of collagen or proteoglycans (or both), but since no quadrupolar signal has been obtained yet from in vitro collagen samples, it is likely that the changes come from variations in the levels of proteoglycans, as described in the literature.

This technique could be used to detect early osteoarthritis by quantitatively monitoring changes in the cartilage protein content using the fast field-cycling MRI scanners developed in our research group.

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References

[1] Sunde, E.P. and Halle, B., *J. Magn. Reson. (2010)*; **203**(2), 257-73
[2] Koenig S.H., *Biophys. J. (1988)*; **53**, 91-96
[3] Grushko et al, *Connect. Tissue Res. (1989)*;**19**(2-4):149-76, Table 2