

Towards a Quadrupolar MRI Contrast (QMRIC) for Detecting Early Degenerative Changes in Cartilage Tissue

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Introduction

The high abundance of ²³Na in tissue, especially in cartilage, offers promising prospect for ²³Na-MRI as a powerful diagnostic method for early detection of cartilage degeneration. While both free and ordered (bound) sodium are prevalent throughout the body, monitoring the levels of the latter is of particular interest due to the anticipated strong correlation between changes in ordered sodium concentration and the early symptoms for most musculoskeletal disorders (1). The double-quantum filtered (DQF) experiment, the Jeener-Broekaert sequences and experiments with shift reagents were previously used to selectively probe sodium signals in different environments. The purpose of the work is to introduce novel pulse sequences based on frequency-swept pulses that can be used for probing cartilage degeneration at early stages via ²³Na MRI, and investigate the correlation between the quadrupolar interactions in cartilage samples as a function of proteoglycan (PG) depletion.

Methods

Recently, we described a pulse sequence based on frequency-swept pulses, which has a number of advantages over currently available methods, including frequency-selectivity (demonstration in Figure 1), low RF power deposition, good broad band behavior, and relative insensitivity to rf inhomogeneity effects. These pulses are tested on several liquid-crystalline model systems, and their behavior as a function of B_0 and B_1 inhomogeneity effects is analyzed. We correlate the variation of quadrupolar coupling constants - QCCs with PG depletion levels. Bovine cartilage samples were treated with a trypsin/PBS (0.2 mg/ml) solution in order to deplete the PGs. The QCCs are measured with both a DQF and the CPS pulse sequence (2) and recorded as a function of depletion time (Figure 2).

Tissue samples show rapid T_1 as well as T_2 relaxation rates, which complicates the application of any coherence transfer sequence. In preliminary experiments we find that pulses as short as 400 μ s produce a good coherence transfer from the satellite to the central transitions. Further numerical optimizations of the rf sequences provide us with the most efficient mechanisms to detect ordered sodium selectively for given ratios between QCC and T_1 and T_2 values. The sequences are tested with model liquid crystals, as well as, with bovine cartilage samples.

Results and Discussion

Figure 1 shows the demonstration of a frequency-selective quadrupolar MRI contrast (QMRIC) mechanism based on the use of frequency-swept pulses. It is possible to selectively transfer the satellite transitions within a certain QCC range to the central transition, where it can be detected with high efficiency. Figures 1a,b show the normal spectra, Figures 1c,d the spectra after central transition saturation, Figures 1e,f the spectra after a coherence transfer from the outer satellite transitions, Figures 1g,h show the spectra after transferring the inner satellite transitions, and Figures 1i,j show the spectra after a transfer of both inner and outer transitions.

Figure 2 shows results from the PG depletion study. The increase of QCCs indicates that PG-depleted samples show regions of increased order. This means that either less accessible PG-sodium environments become visible, or that increased order is observed due to changes in the collagen/PG ratios. After longer depletion steps the order parameter decreases again, indicating that now less accessible PG-sodium regions are depleted, and that the overall structural integrity is lost. These results have direct impact on ²³Na MRI, where quadrupolar contrast, monitored either using DQF or frequency-swept methods can give spatially-resolved information on the functional integrity of cartilage tissue.

Conclusion

We demonstrate that a frequency-selective QMRIC mechanism is possible. Quadrupolar coupling values are further shown to depend on PG depletion levels. Preliminary experiments demonstrate that it is possible to obtain signals from ordered sodium environments with high efficiency in the fast T_1 and T_2 regimes.

References

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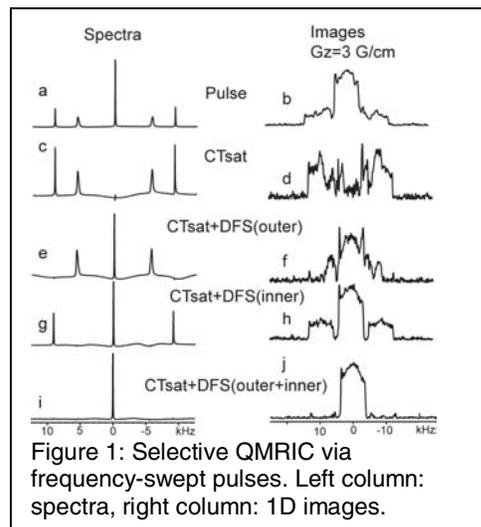


Figure 1: Selective QMRIC via frequency-swept pulses. Left column: spectra, right column: 1D images.

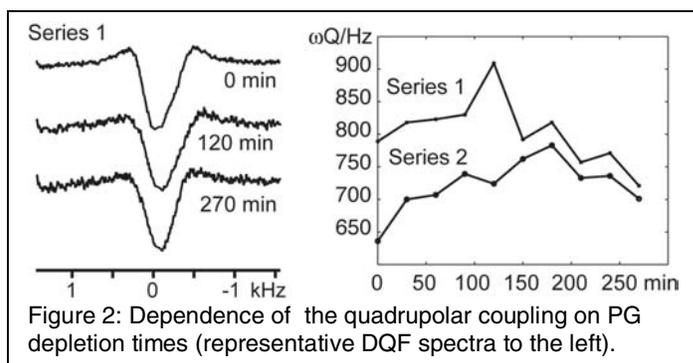


Figure 2: Dependence of the quadrupolar coupling on PG depletion times (representative DQF spectra to the left).