# *In Vivo* Triple-Quantum-Filtered Sodium MRI: Signal Dependence on the RF Pulse-Widths

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## INTRODUCTION

MRI of sodium has been suggested as an attractive complement to proton MRI for in vivo diagnosis and monitoring of disease in humans. Separate observation of the intracellular sodium component (ISC) from the MRI signal could be used to enhance the specificity and sensitivity of sodium MRI for the study of pathology. One of the most promising, non-invasive techniques for monitoring ISC is the triple quantum (TQ) filtration method [1]. Although this technique has been recently used for imaging articular cartilage [2] and human brain [1], its dependence on the data acquisition parameters has not been fully characterized. Because of the weak nature of the TQ sodium signal, characterization of this dependence is of paramount importance for the development of TQ sodium MRI applications.

In this work we demonstrate theoretically, as well as experimentally, that the length of the radio-frequency (RF) pulses is an important parameter for the optimization of the TQ sodium MRI signal. Using the formalism briefly presented in the "Theory" section, the change in TQ signal as a function of the RF pulse-width can be calculated. Our results indicate that for the shortest pulse-widths attainable in clinical scanners (~100μs), TQ sodium MRI signal increases as high as 30% can be obtained.

## THEORY

The typical RF pulse-widths (PW) used for sodium TQ MRI in clinical scanners (~0.5ms) represent a significant fraction of the sodium transversal relaxation times. Therefore, these RF pulses must be considered as non-ideal, and relaxation must be allowed during the time they are applied. Under these conditions, the spin system evolves under the simultaneous action of the Zeeman, static quadrupolar and fluctuating quadrupolar hamiltonian.

Following [3], two sets of differential equations can be used to describe the evolution of the spins (one set 8 by 8, one set 7 by 7). These sets evolve independently during the RF pulses, but are coupled at a change of RF phase. These differential equations were solved numerically to obtain the results presented below (no analytical solutions are available for the general case).

## METHODS

**Data Acquisition:** Sodium 3D data were acquired on a 3 Tesla whole body scanner (GE MS, Milwaukee, WI), using a custom built, dual-tuned ($^{23}$Na/$^{1}$H), dual-quadrature birdcage RF coil [4]. The TQ filter consisted in a sequence of 3 equal amplitude RF pulses $90_{\phi}$-$\tau$-$90_{\phi+90}$-$\delta$-$90_{0}$, 6-step phase cycle [1], followed by twisted projection [5] readout. The TQ signal was maximized by varying the transmit gain (TG), and PW's modified so that the product of the RF pulse amplitudes (PA) and PW remained constant (so that the flip angle is the same).

## RESULTS

Figure 1 presents a comparison between the theoretical (line) and experimental data (dots) for the PW dependence of the 3 pulse TQ signals collected from a small piece of nasal bovine cartilage. Each data point represents the time-integral of the TQ FID at a specific PW, scaled with respect to the 500μs point. A 3 pulse TQ filter (RF PW of 300μs) was used to determine the fast and slow relaxation times (a fit to a difference of two exponential functions yielded $T_{2s}$*=8.54ms, $T_{2f}$*=1.31ms). Additional measurement of the TQ relaxation time (equal to $T_{2s}$*) by varying the evolution time of the TQ coherence in a TQ filter ($T_{2s}$*=8.80ms) is consistent with the value determined above. The theoretical curve was generated assuming the above mentioned relaxation rates, and a zero quadrupolar coupling constant ($\omega_Q$). Addition of a non-zero $\omega_Q$ (or distribution of $\omega_Q$'s) into the theoretical prediction will lead to a steeper decay of the theoretical curve, which is not consistent with the experimental data. Another important finding is that, if the 4-pulse sequence is used (refocusing pulse having the same height as the other RF's, but twice the PW), relaxation during the refocusing pulse leads to additional TQ signal loss (18% for the above mentioned relaxation rates).

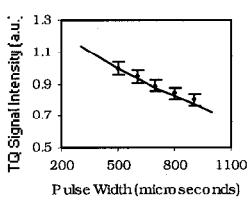


**Figure1:** *Pulse width dependence of the TQ Signal. The dots represent the experimental data, the line the theoretical prediction.*

Figures 2a and 2b present a selection from a three-dimensional (3D) TQ image data set collected on the knee of a normal volunteer, using PW's of 500μs (2a) and 1000μs (2b). As it is readily observable, the signal loss due to relaxation during the RF pulses is significant. Using the relaxation times collected from a single TQ FID from the same volunteer (PW=*500μs*) (T2s*=12.58ms,T2f*=0.75ms), the theoretical signal loss was calculated for a PW increase from 500μs to 1000μs (~38%). The measured signal loss (~36%) is in excellent agreement with our theoretical result (Figure 2c). Using the same relaxation rates, the TQ signal strength for a PW of 100μs was estimated to be 50% higher than that achieved for a PW of 500μs.

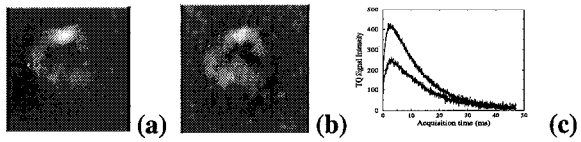


**Figure2: (a-b)** *Partition from a 3D TQ image collected on the knee of a normal human volunteer, using pulse widths of 500μs* and *1000μs, respectively. (c) TQ FID's from the same volunteer, colected with* PW=*500μs (tall curve) and* PW=*1000μs (low curve).*

## CONCLUSIONS

The results presented above demonstrate that relaxation during the RF pulses is an important mechanism of signal loss for a triple quantum filter. Our results indicate that knowledge of the relaxation properties of the tissue allows the accurate estimation of the TQ signal loss accrued during RF excitation. Clinical implementations of TQ sodium MRI should use the shortest RF PW allowed by the scanning hardware and patient safety considerations. Finally, the 3-pulse TQ filter was shown to be less sensitive to this source of signal loss than the 4-pulse TQ-filter.

## REFERENCES

[1] Hancu, I et. al., Magn. Res. Med, In Press.
[2] Borthakur et al., JMR, In Press.
[3] J.R.C. van der Maarel, J. Chem. Phys, **99**, 5646, 1993.
[4] Shen, G. et al., Magn Res Med, **38**, 717, 1997.
[5] Boada, F.E. et al., Magn. Res. Med., **37**, 706, 1997.

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