Double quantum magic angle sodium MRI of the human brain

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Purpose: The selective detection of sodium signal from nuclei in highly ordered environments that exhibit non-zero residual (i.e. non time-averaged) quadrupole interactions ($\overline{\omega}_Q$) is possible with a double-quantum magic-angle sequence (DQ-MA).[1] A spectroscopic version of this sequence has previously been used to demonstrate the presence of non-zero $\overline{\omega}_Q$ in human skeletal muscle and brain in vivo.[2] Investigation of $\overline{\omega}_Q$ is pertinent to tissue sodium concentration quantification, given the signal loss it can cause during the RF pulse in a typical sodium sequence.[3] Alteration of $\overline{\omega}_Q$ may also be interesting to explore in disorders which alter tissue microstructure. The purpose of this study is to create the first DQ-MA *images* of human brain for initial assessment of $\overline{\omega}_Q$ spatial variation.

Methods: All experiments were performed using a 4.7T Varian Inova whole-body scanner and a single-tuned birdcage head coil. Three 250 mL cylindrical phantoms ($[^{23}Na]$ = 200 mM) containing saline, 4% agar gel, and 3% xanthan gum were constructed to demonstrate correct sequence function. Agar and xanthan gum reflect disordered and ordered macromolecular environments respectively.[4] Three healthy volunteers were then scanned. The parameters for the DQ-MA sequence (Figure 1) were: flip angles=90°, 90°, 55°, pulse width=0.3 ms, TR=430 ms, δ=0.3 ms, and τ=2 ms. The value of τ chosen was based on previous study.[2] DQ-MA brain images were acquired with 3 averages for a scan time of 18 minutes. In both phantom and volunteers experiments, triple-quantum-filter (TQF – using parameters optimized for SNR[5]) and single-quantum (SQ – parameters: flip angle=90°, TE/TR=0.5/120 ms, pulse width=0.8 ms) images were also acquired. Twisted projection k-space acquisition (212 projections, twist=0.14, field of view=240 mm, readout duration=12.5 ms, nominal resolution=12 mm isotropic) was used to create all images.

Figure 1: DQ-MA sequence with phase cycling scheme of φ=0, 90, 180, 270. Receiver phase is alternated between 0 and 180 for each phase cycling step. τ and δ refers to preparation and evolution time, respectively.

Results and Discussion: The DQ-MA sequence eliminates signal from all environments in which the nuclear electric quadrupole moment interaction with the electric field gradients experienced is time-averaged to zero (i.e. both saline and agar – Figure 2). Signal is produced from only the xanthan gum phantom, implying the existence of non-zero $\overline{\omega}_Q$ within this phantom (i.e. some *micro*scopic order). The DQ-MA provides unique information relative to TQF where sodium signal is still present in the agar gel. The τ value used in the DQ-MA sequence produces signal from interactions producing $\overline{\omega}_Q$ values in the vicinity of 125 Hz. DQ-MA signal is only a small fraction of SQ signal resulting in images with poor SNR and spatial resolution. Nevertheless, signal from DQ-MA was observed throughout the human brain (Figure 3). One might expect differences in non-zero residual quadrupole interactions of sodium between gray and white matter, but this is not observed in the very low resolution images. Further research is necessary to quantify the distribution of $\overline{\omega}_Q$ throughout the brain, its impact on tissue sodium concentration quantification and its variation in disorders that alter tissue microstructure.

Figure 3: Representative slices from one volunteer showing sodium images acquired using SQ, TQ, and DQ-MA sequences. SQ images were acquired in 24 s to highlight gross anatomy. DQ-MA images show signal throughout the brain in a relatively uniform manner. SNR is 9±2 measured on DQ-MA images from three volunteers. TQF and DQ-MA images were acquired with 3 averages for scan time of 7 and 18 minutes respectively.

Figure 2: SQ shows signal from saline, agar, and xanthan gum whereas DQ-MA provides selective detection of signal from only the sodium nuclei in the macromolecular ordered xanthan gum. TQF shows signal from sodium nuclei with bi-exponential T_2 relaxation which provides a different contrast than DQ-MA. The images are not scaled equally.

References: 1. Jaccard G, et al. J Chem Phys 1986; 2. Reddy R, et al. Magn Reson Med 1995; 3. Joseph PM, et al. Magn Reson Med 1987; 4. Woessner DE. Concepts Magn 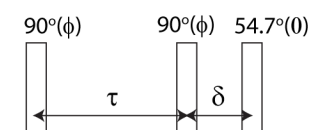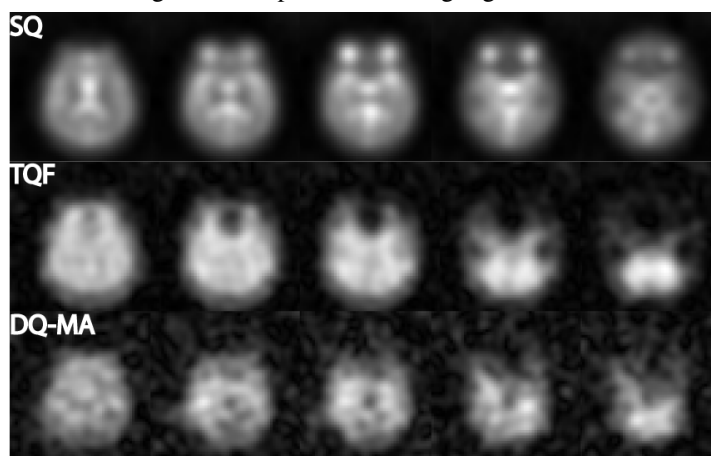Reson 2001; 5. Tsang A, et al. Magn Reson Med 2012;