Intra-cellular Sodium fraction in the human brain at 7T *in-vivo*.

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Introduction

Sodium MRI has been shown to be a useful technique in the studies of several neurological disorders including tumors, stroke [1] and Alzheimer's disease [2]. While the extracellular sodium concentration remains relatively constant as long as there is adequate tissue perfusion, the intracellular sodium density may provide information about cellular and metabolic integrity and ion homeostasis. The observed single-quantum (SQ) sodium signal comes from the weighted average of the extracellular $[Na^+]_{ex}$ and intracellular $[Na^+]_{in}$ sodium content. The two compartments can be differentiated with the help of triple-quantum filtered (TQF) sodium imaging [3,4], as it uses coherence transfer to separate signals from bound and free sodium ions. (Here, we assume that most of the bound sodium is found in the intracellular space). The goal of the present study was to combine the two imaging techniques to obtain intracellular sodium fraction in human brain *in-vivo*.

Figure 1: Schematic diagram of the TQF excitation block superposed with signal evolution and imaging readout.

Theory

The intracellular fraction η is defined as the ratio of the intracellular contribution to the total sodium mass in a voxel. While the SQ image is the weighted sum of the intra- and extra-cellular components, the TQF image is due to the bound component only [5].

$$S_{SQ} = \frac{M_{in}}{5}\left(3e^{-TE/T_f} + 2e^{-TE/T_s}\right) + M_{ex}e^{-TE/T_s}, \quad S_{TQF} = \frac{9M_{in}}{40}\left(e^{-\tau_1/T_f} - e^{-\tau_1/T_s}\right)\left(e^{-TE/T_f} - e^{-TE/T_s}\right), \quad \eta = \frac{M_{in}}{M_{in} + M_{ex}}$$

Methods

Three healthy volunteers were recruited for the study. The study was approved by the local IRB and informed consent was obtained from all subjects. Experiments were performed on a 7T whole-body MAGNETOM scanner (Siemens Healthcare, Germany) with a custom-built dual-tuned TX/RX ^{1}H/^{23}Na head coil [6] and a modified GRE sequence (see Figure 1). The RF excitation train was comprised of three non-selective pulses of 900 μs duration each. Acquisition parameters for the 12-step B0-corrected TQF imaging [7] were 240x240x240 mm^3 FOV with 30x30x24 encoding matrix; TR=150ms, TE=6.8ms, FA=90^0 and τ_1=6.8ms τ_2=150μs. The SQ imaging was performed with the same acquisition parameters as the TQF. The ratio of the SQ and TQF signal intensities was used to estimate the intracellular fraction as described above. Due to long TRs, T_1-weighting was ignored. Slow and fast relaxation constants T_s and T_f were measured from the whole head using a technique similar to [8].

Results and Conclusions

Based on the whole head measurements, the sodium relaxation constants were T_f=2.3 ms and T_s=41.0 ms which are similar to the previously reported values in the rat head at 7T [8]. Several contiguous axial slices of the intracellular fraction maps from a volunteer are shown in Figure 2, along with histograms of intracellular fractions across the brain in each volunteer. The images reveal that the mean intracellular sodium fraction in the brain is 43%. This is in a good agreement with the predicted values between 26% and 57% [9].

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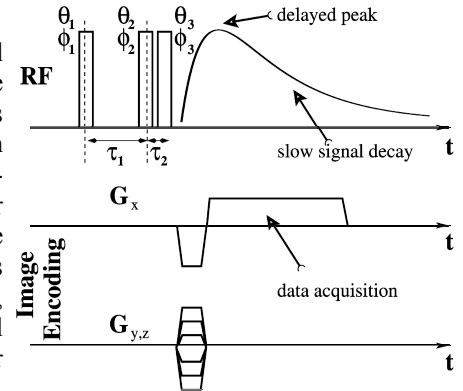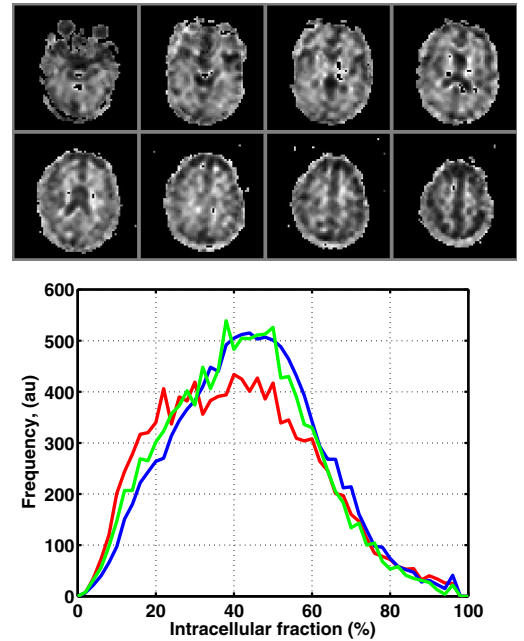
Figure 2: Quantitative map of the intracellular sodium fraction from a volunteer (top) and the histograms of the intracellular fraction across the brain in each of the three volunteers (bottom).

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