Single-sequence single-quantum and triple-quantum imaging of sodium at ultra-high field strengths

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Introduction

Sodium concentration is highly regulated in the human body. Monitoring sodium levels is therefore a good indicator of cell viability [1]. Of particular interest is the intracellular sodium. Triple-quantum filtering has been suggested as a means to observe primarily the intracellular sodium [2]. Single sequence acquisition of triple-quantum filtered (TQF) and single quantum (SQ) sodium has recently been demonstrated [3]. In this work we present a modified imaging approach using two signal-to-noise efficient Twisted Projection Imaging (TPI) readouts at 9.4T.

Materials and Methods

All experiments were performed on a Siemens (Erlangen, Germany) 9.4T whole-body scanner. A home-built birdcage coil was used for imaging. The sequence diagram is shown in Figure 1. The triple-quantum preparation consisted of three 90° hard RF pulses separated by a variable first delay, τ (~ 10ms), and a fixed second delay, δ (40μs). Two individually-designed TPI waveforms were used to collect data. The SQ waveform had a nominal 5mm isotropic resolution and a readout duration of 8ms; the TQ acquisition had a nominal 6mm isotropic resolution and 35ms readout duration. The first readout took place during the first delay τ, and acquired data on the FID of the first pulse and was successively rewound to avoid interference with the triple-quantum preparation. The second readout took place after the third RF pulse and collected the triple-quantum filtered data. A twelve-step phase cycling was used for triple-quantum filtering [4]. An additional 12 steps were added to correct for B0 inhomogeneities [5]. T2*-weighted images were reconstructed from the TQF data by multiplication with appropriate phase factors before combining the averages. Shimming was performed using a double-echo Cartesian sequence on the sodium channel, thereby minimising movement between shimming and measurement. τ and TE2 were optimised before measurement using a global triple-quantum filtered spectrum. The reference voltage was adjusted by fitting a sinusoidal function to the spectral maxima of FIDs with increasing flip angles, α. Data from a healthy volunteer was acquired after informed consent was obtained at 9.4T and according to the local IRB.

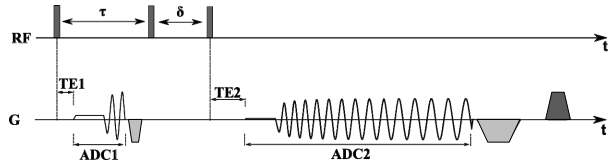

Figure 1 SISTINA sequence diagram. Readout 1 fits between the first two RF pulses and is rewound (light grey gradient). The second readout is considerably longer, rewound (light grey) and spoiled (dark grey).

Results

Results from a phantom containing compartments with distinct sodium concentration in combination with three agarose concentrations are shown in Figure 2. A schematic is shown in Figure 2 (a). Each section is labelled with sodium concentration (top number) and agarose concentration (bottom number). The TQF image (b) shows agarose concentration weighting, while the SQ image (c) shows sodium concentration weighting. The SNR (mean signal divided by its standard deviation) of the red-delineated region-of-interest is 9 and 12 for TQF and SQ images, respectively. *In vivo* results are shown in Figure 3. SQ images (a) show very good CSF delineation and brain structures. The TQF image (b) is necessarily lower in SNR and resolution. Compared to the T2* weighted image (c) of the same slice, the signal dropouts, attributable to the cerebrospinal fluid, are visible. They are marked by red arrows in the TQF image (b).

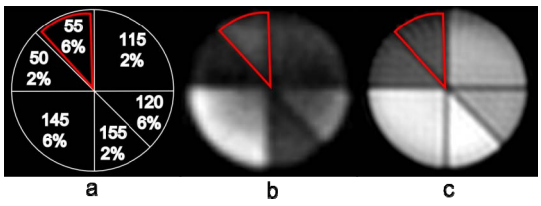

Figure 2 9.4T phantom results. Schematic (a) shows sodium concentration in mmol/l (top) and agarose concentration (bottom). TQF (b) and SQ(c) imaging results are shown. SNR values of the red compartment are 9 (b) and 12 (c).

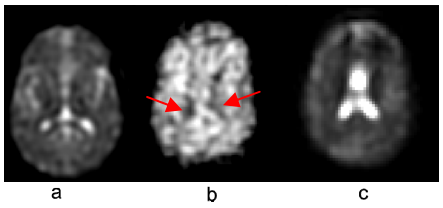

Figure 3 9.4T in vivo results. TSC weighted SQ (a) and TQF (b) image. (c) shows a T2* weighted image showing the same slice as (b). Signal dropout from CSF in the TQF image is marked with red arrows.

Discussion

Phantom images clearly show that the two readouts yield different information. The SQ image provides information about the total sodium content, and the TQF image reveals information about the environment of the sodium ions. Here, the difference in contrasts is generated by the agarose. Although image quality is good, some edge effects are, nevertheless, visible. No flip angle correction has been performed on any of the images, which might increase the image homogeneity, especially considering the high field strength.

In vivo results nicely show brain structures, demonstrating the benefits of the high field strength. TQF images have sufficient SNR to clearly delineate the brain from the background. Triple-quantum filtering removes the CSF signal from the image, but due to partial volume effects, the size of the ventricle appears different in TQ and T2* weighted images. The B0 correction corrects for most inhomogeneities, however, no B1 correction was performed – this is noticeable by the lack of skin signal around the head usually visible in TQF images.

Conclusion

It was shown that good quality triple-quantum filtered and single-quantum sodium images can be obtained from a single combined acquisition at ultrahigh field strengths.

Acknowledgements

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References: [1] Boada et al., C Top Dev Biol 2005 **[2]** Winter et al. JMR 152, 2001 **[3]** Fiege et al. Proc. ISMRM 2011 **[4]** Tanase et al. JMR 174, 2005 **[5]** Matthies et al. JMR 202, 2010