TRIPLE-QUANTUM-FILTERED SODIUM IMAGING AT 9.4 TESLA

Christian Mirkes[1,2], G. Shajan[1], Jonas Bause[1], Kai Buckenmaier[1], Jens Hoffmann[1], and Klaus Scheffler[1,2]

[1]*High-Field MR Center, Max Planck Institute for Biological Cybernetics, Tuebingen, BW, Germany,* [2]*Department for Biomedical Magnetic Resonance, University of Tübingen, BW, Germany*

PURPOSE

Sodium triple-quantum-filtering (TQF) is an imaging technique with an intrinsically low signal-to-noise ratio (SNR). Since the SNR scales approximately linearly with the main static magnetic field (B_0), UHF scanners can be used to mitigate this problem. Unfortunately, the specific absorption rate (SAR) is proportional to B_0^2 and hence the repetition time (TR) or the used flip angles for the TQ preparation have to be reduced to comply with the prescribed power deposition limits. As a matter of fact, the TQ acquisition becomes less efficient and some of the sensitivity offered by UHF is lost. In this study, the flip angles (FA) of the TQ preparation were modulated in such a way that SAR is reduced while preserving most of the TQ signal.

METHODS

All measurements were performed on a Siemens (Erlangen, Germany) 9.4 T human whole-body MR scanner. A triple-layered proton/sodium coil was used for the acquisition of the proton (399.7 MHz) and sodium (105.7 MHz) signal1. A standard three-pulse preparation was used to generate multiple-quantum coherences. The basic sequence diagram is shown Figure 1a. The TQ coherences were filtered out with a two-times-six step phase cycling scheme in order to allow for B0 correction2. SQ images (Res 2x2x5 mm3, Partitions 48, Spiral interleaves 120, TD1 1.5 ms, TE1 0.8 ms, TR 200 ms) were acquired with a stack of spirals3 during the preparation time (τ) between the first and the second RF pulse. The second and third pulse (TD2,3 = 1 ms) were implemented as a single phase-modulated pulse, which avoided adding an additional delay for coil detuning and tuning. A double-spiral was used to efficiently acquire the TQ signal (Res 5x5x5 mm3, Partitions 48, Interleaves 10, τ = 5.5 ms). The gradient waveforms were designed such that the second echo time (TE2) coincided with the maximal TQ signal. The acquisition time for the in vivo images was 20 min. In order to decrease SAR, the flip angle of the three pulses of the TQ preparation was smoothly reduced towards the edge of k-space along the partition-encoding direction:

$$\alpha_{1,2,3}(p) = FA_{1,2,3} \cdot \left[\cos^2\left(\frac{\pi}{2}\left(\frac{2p}{N_{\mathrm{Par}}} - 1\right)\right)R + (1-R)\right] \quad \text{for} \quad p = 0 \ldots N_{\mathrm{Par}} - 1,$$

where R controls the amount of apodization, p is the partition index, and N_{Par} the total number of partitions. As given by the previous equation, the highest flip angle was used for the central partitions, which are most relevant for image contrast and a lower flip angle for the outer partitions. The FA modulation acts like a fliter on k-space and influences the full-width-at-half-maximum (FWHM) of the point-spread function (PSF). Simulations with a SAR limit of 3.2 W/kg were performed to estimate the final resolution in partition-encoding direction and the sensitivity ($\propto SNR/\left(\sqrt{TR} \cdot FWHM\right)$).

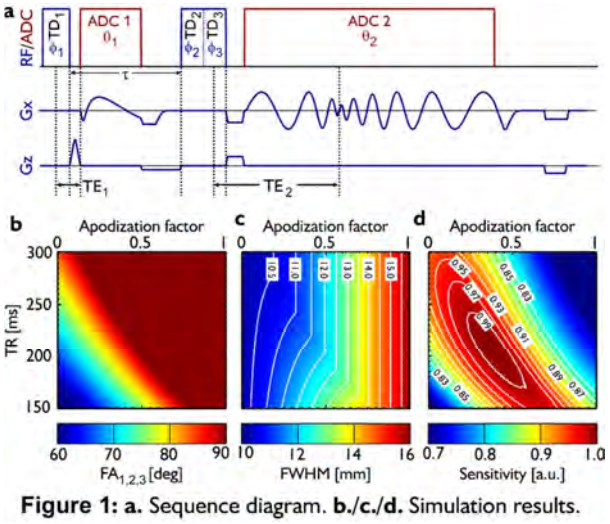

Figure 1: a. Sequence diagram. **b./c./d.** Simulation results.

RESULTS

Figure 1b shows the maximal FA for the TQ preparation still fulfilling the SAR limits as a function of TR and R. The FWHM of the PSF along the partition-encoding direction for the TQ acquisition is shown in Figure 1c. Even without flip angle apodization the resulting spatial resolution is below its nominal value (5 mm). The reason for this is primarily the Hanning filter which was applied to k-space. Figure 1d demonstrates that a higher sensitivity compared to the standard acquisition (R=0) can be achieved for each value of TR if flip angle apodization is used. Figure 2a shows the obtained SQ images in one volunteer. Owing to the high in-plane resolution, fine anatomical details such as the CSF-filled sulci can be discerned. Compared to the SQ acquisition, the TQ images (Fig. 2b) exhibit a much lower spatial resolution. The coarse nominal resolution is further reduced by the use of flip angle apodization (R=0.5) and the transverse relaxation of the received signal. As a matter of fact, the expected signal dropouts in the ventricles are less pronounced. Signal dropouts near the nasal cavities could not be avoided even with B_0 correction.

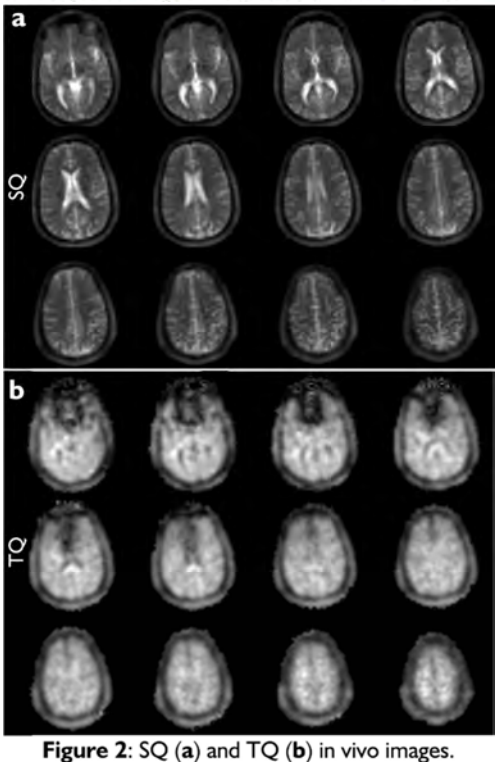

Figure 2: SQ (**a**) and TQ (**b**) in vivo images.

DISCUSSION & CONCLUSION

This study has shown that it is possible to acquire B_0 corrected TQF images at 9.4 T in a clinically acceptable measurement time of 20 min. In order to reduce the time needed to sample the entire k-space, a highly efficient double-spiral trajectory was used instead of a Cartesian or radial readout. Additionally, the double-spiral readout permitted to acquire data even before the delayed formation of the TQ signal peak. The reduction of the TR permitted improving the sensitivity and efficiency of the SQ/TQ acquisition as demonstrated by the simulations. However, the nominal spatial resolution along the partition-encoding direction and the number of partitions might have to be increased in order to compensate for the broadening of the PSF due to the flip angle apodization. In conclusion, TQF benefits greatly from the increased SNR available at UHF. However, the used imagining sequence must be designed in such a way that stringent SAR constraints do not cancel out this advantage.

REFERENCES 1. Shajan et al. ISMRM-ESMRMB 2014;22:620 2. Fleysher et al. NMR Biomed. 2010;23:1191–8. 3. Qian et al. Magn. Reson. Med. 2012;68:227–233.