Biexponentially Weighted Sodium Imaging with Higher SNR Efficiency

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Introduction

Triple-quantum filtered (TQF) sodium MR signal mainly originates from the intracellular compartment [1]. Pathological conditions in tissue which are associated with small changes in the cellular sodium ion gradient can be detected with TQF [2]. As the SNR is low, a biexponentially weighted sodium (BWS) imaging technique was introduced [3] which yields a similar contrast as TQF. However, due to SAR restrictions repetition time (TR) becomes impractically long for both imaging techniques at field strengths $B_0 \geq 7$ T. In this work, a sequence is introduced which only requires two instead of three hard $\pi/2$-pulses for BWS images. The lower SAR enables shorter TR and thus shorter acquisition times and higher SNR efficiency.

Materials & Methods

The pulse sequences were implemented on a 7-Tesla whole-body MR system (Magnetom 7 T, Siemens, Erlangen, Germany). A double-resonant ($^1H/^{23}Na$) birdcage coil (Rapid Biomed GmbH, Würzburg, Germany) was used for the measurements. Sequence diagrams are shown in Fig. 1. A spin density weighted (SD) and a single-quantum filtered (SQF) or TQF image are acquired during the two density adapted 3D radial readout gradients [4]. The images are weighted to account for T_2^* relaxation of the cerebrospinal fluid (CSF) and subtracted to generate a BWS image:

$BWS = SD - \exp((-TE_1+\tau_1+TE_2)/T_2^*) * SQF$ (two pulse method).

Single-Quantum Filtration Triple-quantum and possibly double-quantum coherences are excited after the second RF pulse and thus are lost for detection. Hence, the image acquired after the second pulse is automatically filtered for single-quantum coherences. A two step phase-cycling is used to eliminate signal contributions from longitudinal magnetization after the second pulse ($\varphi_1 = 0°$; $\varphi_2 = \pm\pi/2$). In vivo experiments are used to compare the proposed method (2P-BWS) with the three pulse (3P) BWS method and conventional TQF sodium imaging.

Sequence parameters Figure 3: TE_1/TR = 0.3/158 ms, τ_1 = 11 ms, T_{RO} = 10 ms, Δx^3 = $(7.5\ mm)^3$, projections = 2000, T_A = 31:36 min. Fig. 3a+b/3c: TE_2 = 11/0.3 ms, τ_2 = 50 µs/-, phase cycling steps = 6/2, averages = 1/3.

Fig. 4a/4b: TR = 160/107 ms, Δx^3 = $(5.5\ mm)^3$, averages = 3/2, other parameters: as 2P-BWS in Fig. 3.

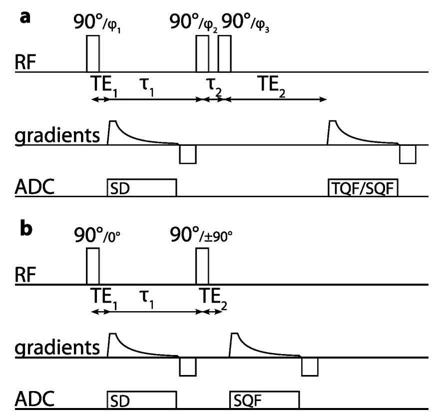

Fig.1: Sequence diagram for 3P-BWS or TQF (a), and for the proposed 2 pulse method (b)

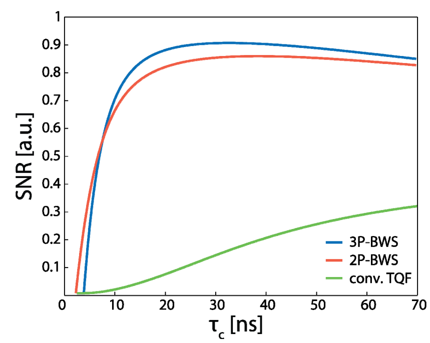

Fig.2: Theoretical SNR of the compared sequences (with the same TR values)

Results & Discussion

2P-BWS images generate a contrast comparable to 3P-BWS images (Fig. 2 and 3). All implemented methods allow the acquisition of biexponentially weighted images with good suppression of signal originating from sodium ions in CSF (Fig. 3 and 4). All sequences were compared in phantom experiments prior to in vivo application (data not shown). Phantom experiments also show good suppression of pure saline solution (0.9 %).

TQF and BWS images of a healthy volunteer are compared in Fig. 3. The 3P-BWS image is generated from the same dataset as the TQF image. Eyes (not shown) and ventricles show reduced signal intensity. SNR is improved by a factor of about 3 for BWS images. The 3P-BWS image is less affected by artifacts in regions which are prone to B_0 inhomogeneities compared to 2P-BWS (Fig. 3b and 3c). In 3P-BWS some of the contributing signal pathways are refocused at the time of signal acquisition and thus B_0 inhomogeneities are partly compensated.

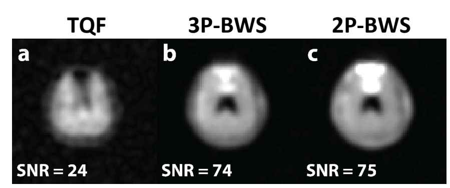

Fig.3: Conventional TQF, 3P-BWS, and 2P-BWS in vivo head images (healthy volunteer, male, 49 years).

Fig. 4 shows in vivo images of another healthy volunteer acquired with 2P-BWS. In Fig. 4a TR was set to a value which would have been required for conventional TQF imaging. In Fig. 4b TR was set to satisfy SAR limitations of the 2P-BWS sequence. Both measurements were performed with the same total acquisition time (2 vs. 3 averages). As expected, an increase in SNR of sqrt(3/2) is obtained in the latter case (Fig. 4b).

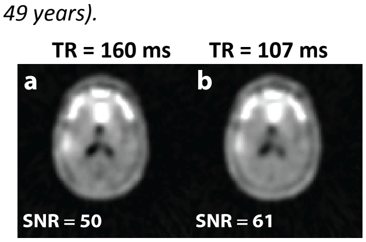

Fig.4: 2P-BWS images (healthy volunteer, male, 30 years) acquired with different TR and the same measurement time.

Conclusion

In this study a new method for generating BWS images is presented. Images show an up to 3 times improved SNR compared to TQF with the same measurement parameters. Measurement time can be shortened in 2P-BWS sequences by reducing the number of averages (only two are required for 2P-BWS) or by reducing TR (as SAR is only about 2/3 of that of TQF and 3P-BWS sequences) resulting in better SNR efficiency.

References

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