FAST SODIUM MRI OF THE HUMAN BRAIN USING A BALANCED STEADY-STATE FREE PRECESSION SEQUENCE

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Purpose: Sodium magnetic resonance imaging (MRI) sets its focus of research primarily on the measurement of tissue sodium concentration with the attempt to distinguish between intra- and extracellular space as well as the investigation of multiple quantum coherences. An alternative is represented by sodium MRI exhibiting relaxation-based contrast. Based on [1], the goal of this work is to develop a sequence to explore the feasibility and properties of relaxation-based sodium MRI using phantoms as well as *in vivo*. A conclusion of whether the findings in [1] can be reproduced independently should be reached. Furthermore, if the method proves to be feasible, the extent of advantages and its usefulness in clinical application will be investigated.

Methods: Measurements were performed on a 3 T whole-body MR system (Magnetom Trio, Siemens Healthcare, Erlangen, Germany) with a double-resonant (^{1}H/^{23}Na) birdcage head coil. Phantoms containing 0.9% saline solution with 0%-5% agar were used. The gradient echo sequence presented in this work implements a density-adapted 3D radial acquisition technique to sample the k-space [2]. It employs rewinder gradients to fully refocus the remaining longitudinal and transverse magnetization, leading to the formation of a steady-state for both magnetizations. Phantom and *in vivo* imaging results of this balanced steady-state free precession sequence (b-SSFP) were compared with the outcome of the fast low-angle shot sequence (FLASH), which differs from b-SSFP in its application of gradient spoilers to destroy the remaining magnetization instead of preserving it. Phantom: Up to 20 linear and Kaiser Bessel (KB) preparation pulses [3] were tested on phantoms using b-SSFP to investigate their influence on the signal development during transient state, with parameters *TE*=1.9ms, *TR*=17ms, t_{RF}=3660µs (RF pulse length), $\alpha_{b\text{-}SSFP}$=90° (RF flip angle) and t_{ACQ}=1.7-2s (acquisition time). Furthermore, phantoms were scanned using b-SSFP and FLASH to compare signal-to-noise ratios (SNR) and contrast-to-noise ratios (CNR) of both methods with *TE*=[1.9, 3, 4, 5, 6, 7, 8, 9]ms, *TR*=17ms, t_{RF}=3750µs, $\alpha_{b\text{-}SSFP}$=90°, t_{ACQ}=6:48min, t_{read}=5ms (readout time), 8000 projections, three averages and an isotropic resolution of 4mm. *In vivo*: A healthy male volunteer was scanned using both b-SSFP and FLASH with *TR*=17ms, *TE*=[1.9, 3.4, 4.9]ms, t_{RF}=3750µs, $\alpha_{b\text{-}SSFP}$=90°, t_{ACQ}=12:45min, t_{read}=8.8ms, 25000 projections, three averages and an isotropic resolution of 3mm.

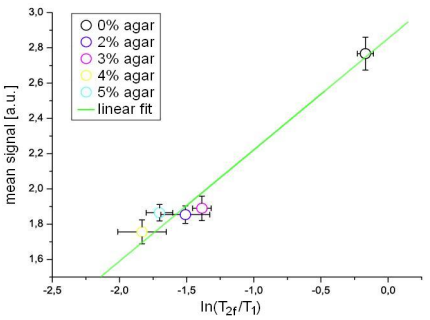

Figure 1: *Mean signal values of phantoms with 0%-5% agar obtained from b-SSFP imaging are plotted and fitted linearly to investigate the contrast dependence of ln(T_{2f}/T_1) proposed by [1].*

Results/Discussion: No considerable advantage of the KB prepulses were found over the linear prepulses in matters of sodium b-SSFP MRI. For the parameter setting used in this work,18-20 prepulses are recommended. Compared with FLASH, a substantial enhancement of CNR of saline/agar was achieved in phantom measurements for b-SSFP, as well as a 27% increase of SNR for the saline and a consistently high SNR for the agar environment. The contrast dependence of ln(T_{2f}/T_1) for sodium nuclei with fast bi-exponential decay [1] could be cautiously confirmed (Fig. 1). *In vivo* measurements (Fig. 2) using b-SSFP delivered an elevation of SNR for cerebrospinal fluid (CSF) (+41%) and grey matter (GM) (+8%), and a decrease of SNR for white matter (WM) (-24%) compared with FLASH (Fig. 3). The CNR of GM/WM, CSF/GM and CSF/WM is therefore higher by a factor of 2.69, 2.08 and 2.24, respectively. Biological tissues have macromolecules of varying type and size, providing for different relaxation-based contrasts. The axons of WM are myelinated, while those of GM are not. The comparatively ordered structure of WM might be responsible for the relaxation-based contrast difference between WM and GM. Therefore, changes of the macromolecular composition might be detectable using b-SSFP. The screening process and patient monitoring of pathological findings associated with such changes could possibly benefit from supplementary information provided by b-SSFP. Such diseases include cartilage degradation and degenerative diseases of the central nervous system associated with demyelination.

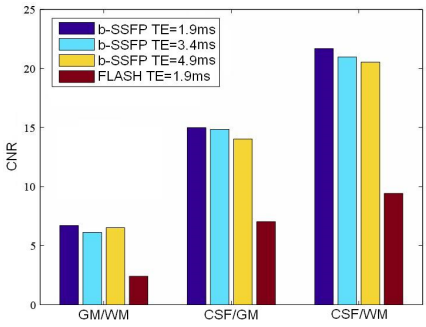

Figure 3: *CNR in vivo. The average CNR realized by b-SSFP is by a factor of 2.69 (GM/WM), 2.08 (CSF/GM) and 2.24 (CSF/WM) higher than that by FLASH.*

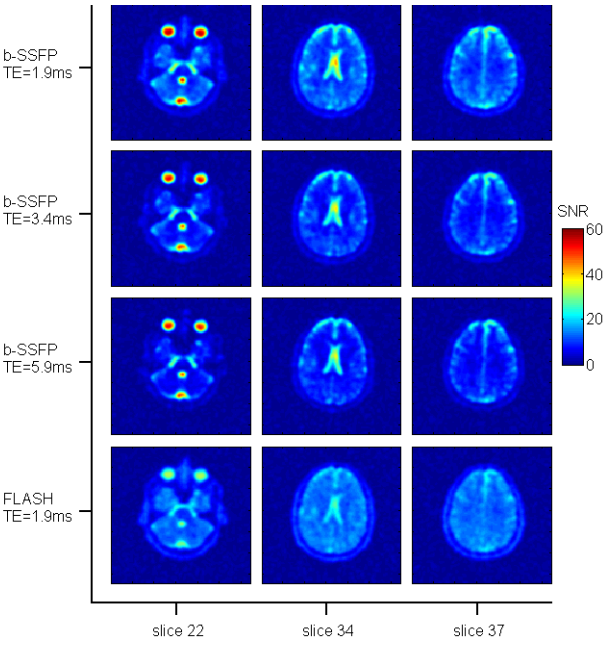

Figure 2: *In vivo SNR images (FOV=192x192mm², 128x128 matrix) in the transverse plane of a healthy volunteer. Each row is assigned to different slices of the same measurement, and each column to the same slice from different measurements. A decrease of SNR can be discerned with increasing TE in the b-SSFP images. Additionally, a higher contrast is visible for CSF/brain tissue and GM/WM for b-SSFP than for FLASH.*

Conclusion: A b-SSFP sequence with 3D density-adapted radial k-space sampling to explore relaxation-based contrast was successfully developed and implemented for sodium imaging for phantom and *in vivo* imaging. It was shown that elevated CNR can be established without reducing SNR. The obtained images are based on a different signal formation mechanism than conventional FLASH imaging. The b-SSFP sequence offers a novel contrast dependence with a high CNR regarding saline/agar as well as fluid/environment with a higher degree of order, capable of possibly bringing forth an alternative means of pathology detection and monitoring to assess the extent and degree of tissue degradation.

References: [1] Stobbe et al., MAGMA, 2003;27(1):21-33 [2] Nagel et al., MRM, 2009;62(6):1565-1573 [3] Le Roux. J Magn Reson, 2003;163(1):23-37