Parameter Optimization for 7T ^{23}Na-MRI

A. M. Nagel[1], S. Schmitter[1], M. Bock[1], E. Moser[2,3], W. Semmler[1], and L. R. Schad[4]

[1]Medical Physics in Radiology, German Cancer Research Center, Heidelberg, Germany, [2]MR Centre of Excellence, Medical University of Vienna, Vienna, Austria, [3]Institute for Biomedical Engineering and Physics, Medical University of Vienna, Vienna, Austria, [4]Computer Assisted Clinical Medicine, Faculty of Medicine Mannheim, University Heidelberg, Mannheim, Germany

Introduction

^{23}Na-MRI suffers from low signal-to-noise ratio (SNR) due to low *in vivo* abundance (≈ 50 mM) of the ^{23}Na nucleus. In tissue, the ^{23}Na signal decays bi-exponentially, with a short/ long component of T_{2s} = 0.5-8 ms/ T_{2l} = 15-30 ms. Therefore, non-cartesian pulse sequences with short echo times are a prerequisite for SNR efficiency. Higher field strengths improve the SNR [1], but lead to altered relaxation times and stronger B_0-inhomogeneities. The latter is in particular problematic for non-cartesian imaging sequences, as used for ^{23}Na-MRI. Theoretically, a linear increase in SNR with B_0 is anticipated. T_2^* is expected to become shorter with higher field strength and T_1 times should increase. The purpose of this study is to provide parameters for the optimization of ^{23}Na-MRI protocols at 7T.

Methods

T_1 and T_2^* relaxation times were measured to optimize the imaging parameters of 3D radial ^{23}Na MRI protocols. In particular, a conventional 3D projection reconstruction sequence (3DPR) [2] and a density adapted projection reconstruction sequence (DA-3DPR) [3] were used. Using double-resonant (^{1}H/ ^{23}Na) birdcage coils (Rapid Biomed GmbH, Würzburg, Germany; inner coil diameters: 25.0 cm (1.5 T), 26.5 cm (3 T) and 26 cm (7 T)), SNR and image quality were investigated at three field strengths (1.5/ 3/ 7 T; Magnetom Avanto, Magnetom Tim Trio, Magnetom 7 T, Siemens Medical Solutions, Erlangen, Germany). To calculate T_2* maps, a multi-echo DA-3DPR imaging sequence was used with the following parameters: TE = 0.5/ 7.2/ 14/ 21/ 28/ 35 ms; TR = 80 ms; 13000 projections; T_{RO} = 5 ms; 1 average, voxel size: 4x4x4 mm^3.

T_1 measurements using a global inversion recovery sequence were performed on 2 phantoms, containing 0.6% NaCl solution, 0% and 5% agarose gel. Additionally, the averaged T_1 value of a volunteer's brain was measured to provide values for the Ernst angle. Although the ^{23}Na T_1 and T_2 relaxations are bi-exponential, mono-exponential fits have been performed to estimate the relaxation times in both cases with better reproducibility.

^{23}Na images with suppressed fluid signal were acquired with an inversion recovery DA-3DPR imaging sequence (DA-3DPR-IR), to investigate possible T_1 changes. Parameters: TE = 0.2 ms (1.5 T); TE = 0.3 ms (3 T); TE = 1.05 ms (7 T); TR = 124 ms; TI = 34 ms; 5000 projections; 1 average; voxel size: 5x5x5 mm^3; Hanning filtering was applied.

^{23}Na images were acquired with 3DPR and DA-3DPR imaging sequences using the following parameters: TR = 50 ms, TE = 0.2 ms (1.5 T and 3 T), TE = 0.5 ms (7 T), T_{RO} = 40 ms; α = 77°, 13000 projections, 1 average, voxel size: 4x4x4 mm^3.

Results

Sagittal slices of ^{23}Na T_2^* maps are shown in Fig. 1. No significant differences between 3 T and 7 T are found for liquor, whereas in brain tissue and close to the paranasal sinuses slightly higher values were observed at 3 T (Fig. 1). T_1 of agarose gel and the averaged T_1 time of the whole brain increase with field strength, whereas for pure NaCl solution no significant differences between the three field strengths were observed (Tab. 1). The latter is in good agreement with the fact, that the same inversion time (TI = 34 ms) could be used at all field strengths to suppress the liquor signal (Fig. 2).

^{23}Na images of a healthy human brain are shown in Fig. 3. As previously demonstrated for 3 T [3], the DA-3DPR acquisition scheme leads to increased SNR as compared to 3DPR sampling also at 7 T. The SNR increase with field strength is shown in Fig. 4.

In the vicinity of the paranasal sinuses (Fig. 3; marked by arrows) extinctions markedly degrade image quality, especially at 7T using 3DPR sampling. With the DA-3DPR sampling scheme, these extinctions are less pronounced.

Discussion

The theoretically expected approximately linear increase in SNR with field strength (a factor of 2 from 1.5 T to 3.0 T and a factor of 2.3 from 3.0 T to 7.0 T) could be confirmed (Fig. 4), with minor deviations that can be attributed to relaxation effects. The smaller increase in SNR with B_0 for brain tissue can be attributed to alterations in T_1 relaxation times, whereas for liquor the relaxation times are approximately independent from B_0. The less pronounced SNR increase with field strength for the IR-sequence, can be attributed to the longer echo time, that was used at 7 T to be conform with SAR limitations and due to the T_1 times of liquor and brain tissue that should be closer to each other at higher field strengths, in accordance with the observations shown in Tab. 1 and Fig. 2.

The constant T_1 times for pure NaCl solution and liquor can be attributed to short correlation times τ_C, which means that the motionally narrowing regime ($\omega_0\tau_C << 1$) still holds for higher field strengths (larger ω_0). In agarose gel the term $\omega_0\tau_C$ can not be neglected and thus T_1 relaxation increases with field strength.

In conclusion, the measured small alterations in relaxation times lead only to minor deviations from the linear SNR increase and enable an easy adaption of existing imaging protocols from lower B_0-fields. Furthermore, it was shown that appropriate sequence designs, such as the DA-3DPR sequence can reduce degradations of image quality due to B_0-inhomogeneities even at 7 T.

References

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[2] Nielles-Vallespin et al.; MRM (2007); 57: 74-81
[3] Nagel et al.; In: Proceedings of the 16th Annual Meeting of ISMRM (2008); p3254

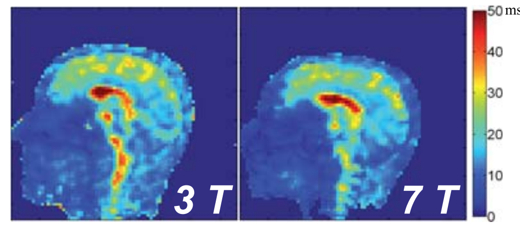

Fig. 1. ^{23}Na T_2^* maps acquired at 3 T and 7 T.

Tab. 1. T_1 – values of 0.6% NaCl-solution containing 5% agarose gel, pure NaCl-solution and the average value of the whole human brain, measured at different field strengths.

B_0 [T]	1.5	3.0	7.0
T_1 (5% agar. gel) [ms]	24.9	29.9	36.0
T_1 (pure NaCl) [ms]	56.5	55.2	56.1
T_1 (human brain) [ms]	33.3	38.6	44.1

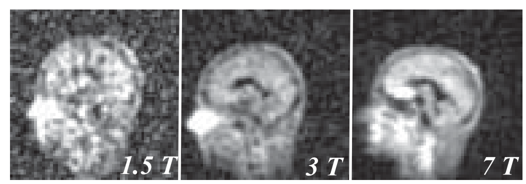

Fig. 2. DA-3DPR-IR ^{23}Na images with suppressed fluid signal.

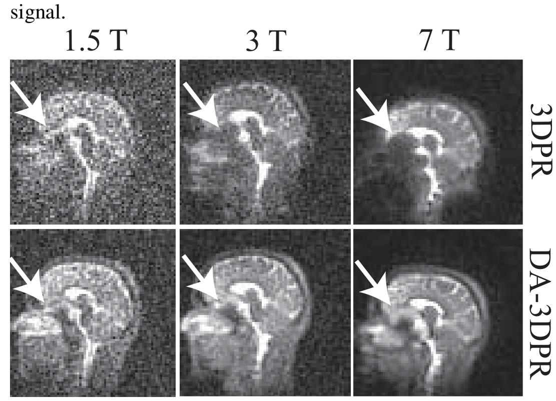

Fig. 3. Images of 3D ^{23}Na brain data sets acquired with the 3DPR and the DA-3D-DPR acquisition scheme at 1.5 T, 3T and 7T. Areas susceptible to extinctions are marked by arrows.

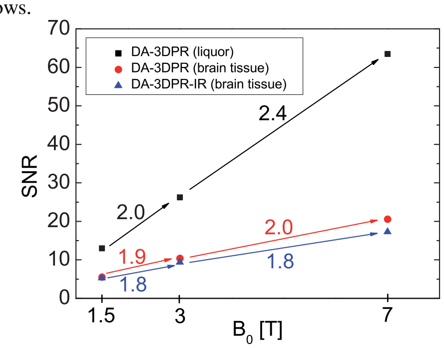

Fig. 4. SNR values of the DA-3DPR images shown in Fig. 3 and of the DA-3DPR-IR images. The numbers on the arrows indicate SNR increase from 1.5 T to 3 T and from 3 T to 7 T.