Evaluation of Radio-Frequency Field Mapping Methods for Quantitative Sodium MRI at 3 Tesla

Jonathan Lommen[1], Simon Konstandin[1], Philipp Krämer[1], and Lothar R. Schad[1]
[1]*Computer Assisted Clinical Medicine, Heidelberg University, Mannheim, Germany*

Introduction

Total tissue sodium concentration (TSC) has been proven to be a non-invasive measure of tissue viability due to its direct connection to the functionality of the sodium-potassium pump in cells' membrane.[1] Quantitative sodium (^{23}Na) measurements must be corrected for intensity variations arising from inhomogeneous excitation and reception profiles. For proton MRI a number of radio-frequency (rf) mapping methods exist. However, up to now this bias is often neglected in sodium MRI due to the low signal-to-noise ratio (SNR) and fast signal decay. These difficult imaging conditions place altered requirements compared to ^{1}H rf mapping and an optimal method has not yet been established. In this work, the most common rf mapping methods have been experimentally evaluated and compared for ^{23}Na MRI. Taking the rf excitation bias into account, *in vivo* TSC quantification can be further improved.

Methods and Materials

Phantom measurements have been conducted to evaluate the quality of the mapping methods statistically and for qualitative comparison rf field maps on a large phantom (Ø 200 mm) have been acquired. The mapping methods are the double-angle (**DAM**) [2], the phase-sensitive (**PS**) [3], the Bloch-Siegert shift (**BSS**) [4] methods and the actual flip-angle imaging (**AFI**). [5] All measurements were carried out on a 3 T whole-body scanner (Magnetom TIM Trio, Siemens Healthcare, Erlangen, Germany) employing a double-tuned (^{1}H/^{23}Na) birdcage head coil (Rapid Biomedical GmbH, Würzburg, Germany) on a homogeneous Siemens phantom and on an in-house built phantom. All mapping methods were implemented into a 3D radial density-adapted sequence [6] with a readout time (RO) of 10 ms and 5 mm nominal isotropic resolution. The respective parameters were: **PS**: 90°-180° pulses, **BSS**: Fermi pulse of 5 ms, 2 kHz off-resonance and FA = 540° (478° for the smaller phantom), **DAM**: flip angles of 60°/120° and **AFI**: FA = 60° and n = 5 (50° rf spoiling increment). In the same order echo times were 0.14/5.12/0.22/0.10 ms and 0.16/5.13/0.22/0.11 ms for the phantoms. The DAM requires a long repetition time of TR = 300 ms (= 5T_1 of phantom) resulting in a total scan time of 31:42 min. To achieve a fair comparison RO times and total acquisition times were kept constant for all methods. For the BSS and the PS four measurements could be realized in the same time (TR = 75 ms) and eight for the AFI (TR_1 = 13 ms). Employing the PS technique *in vivo* rf mapping of the head has been performed on a male volunteer in 11:10 min with 5 mm nominal isotropic resolution, RO time = 20 ms, TE = 0.19 ms and TR = 90 ms.

Results and Discussion

Normalized rf maps are shown in Figure 1. The rf map by the PS (a) exhibits lowest noise and the coil profile is clearly visible. The BSS (b) is noisier and gives a higher field estimate than the latter. DAM (c) still yields a reasonable estimate but the AFI (d) shows high noise and deviates from the other maps. All methods were analyzed quantitatively by correcting the signal of a homogenous phantom and calculating the mean and standard deviation for every slice (Figure 2). The PS method shows the best properties because TE is not extended and due to the phase encoding of the rf field it should theoretically not exhibit T_1 contrast. Thus, it can be either applied with short TR for rapid rf mapping or in fully relaxed conditions using the magnitude data for quantification. However, slight T_1 contrast is visible for short TR. The same applies to BSS but the long TE decreases SNR due to the fast transversal decay of ^{23}Na signal. The DAM requires long TR to avoid T_1 weighting and exhibits lower SNR because of smaller flip angle. The high noise susceptibility of the AFI method renders it not applicable to ^{23}Na MRI. Generally, amplitude-based methods (DAM, AFI) result in higher noise level due to low SNR for small flip angles whereas phase-based methods (PS, BSS) often require longer preparation phases which extend TE but are less T_1 sensitive. Further increase in SNR can be obtained by longer RO times. The damping of higher frequencies (blurring) is not problematic since the rf inhomogeneities vary slowly. To our knowledge only the DAM has been used for TSC quantification [7] but not the superior PS method. An *in vivo* acquisition of a human head employing PS is shown in Figure 3. Slight off-resonance effects can be found at the nasal cavities but are only weakly expressed due to the fast RO scheme.

Conclusion

Quantitative information on tissue sodium content requires correction of the coil profile. The low SNR of sodium demands very efficient rf mapping to maintain acceptable acquisition times and reduce uncertainties introduced by the rf field correction. Four common rf mapping techniques have been adapted for ^{23}Na MRI to find the most appropriate one. The phase-sensitive approach appears to be the best choice because of its short TR and high SNR. Employing the PS mapping technique rf biasing can be corrected while also providing two image data sets for quantification. This enables fast and more accurate determination of tissue sodium content.

References

1. Sandstede et al. MRM 52: 545-551 (2004)
2. Insko and Bolinger. JMR A 103: 82-85 (1993)
3. Morrell. MRM 60: 889-894 (2008)
4. Sacolick et al. MRM 63: 1315-1322 (2010)
5. Yarnykh. MRM 57: 192-200 (2007)
6. Nagel et al. MRM 62: 1565-1573 (2009)
7. Lu et al. MRM 63: 1583-1593 (2010)

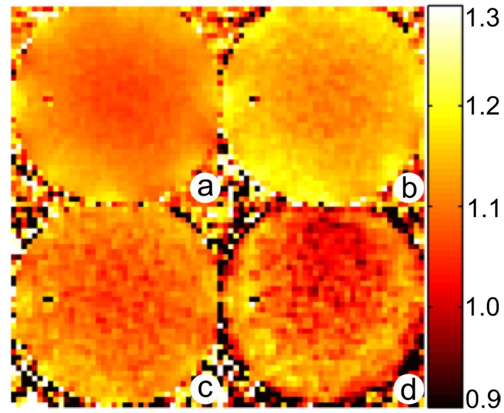

Figure 1*: Normalized rf maps of a homogeneous slice acquired with a birdcage coil: PS (a), BSS (b), DAM (c), and AFI (d). The birdcage profile is clearly observable. The PS method shows highest SNR. BSS and DAM both exhibit more noise. AFI does not yield sufficient SNR.*

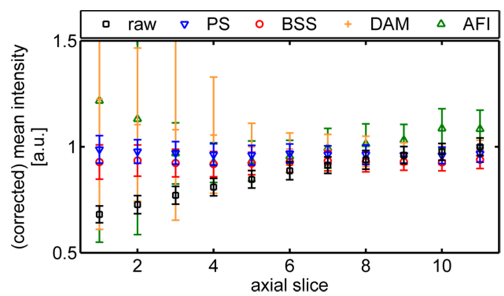

Figure 2: *Mean value over axial slices of corrected and uncorrected signal intensity (black). The intra-slice standard deviation is depicted as error bars. To the left the field becomes weaker as seen in the uncorrected signal intensity. AFI and DAM yield increasing variations for weaker field. PS exhibits the smallest variations and a constant mean value as expected for a homogenous sample.*

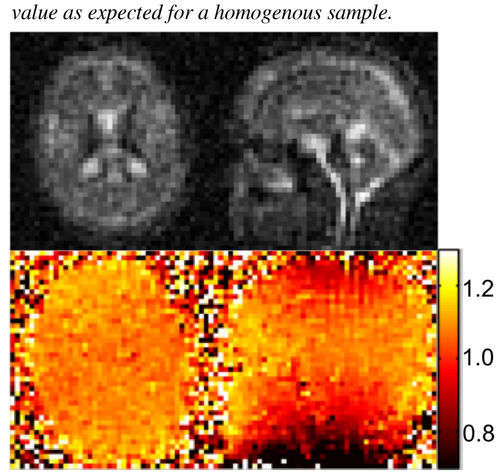

Figure 3: *Axial (left) and sagittal (right) views of sodium magnitude image (top) and rf map (bottom) of a male volunteer using the PS method with TR = 90 ms, 5 mm resolution and an acquisition time of 11:10 min.*