Influence of B_0 and B_1 inhomogeneity on measured cardiac ^{23}Na signal

Johanna Lott[1], Tanja Platt[1], Nicolas G.R. Behl[1], Peter Bachert[1], Mark E. Ladd[1], Armin M. Nagel[1,2]
[1]*Medical Physics in Radiology, German Cancer Research Center (DKFZ), Heidelberg, Germany,* [2]*Institute of Radiology, University Hospital Erlangen, Friedrich-Alexander-University Erlangen-Nürnberg (FAU), Erlangen, Germany*

Target audience: Scientists interested in quantitative cardiac ^{23}Na MRI.

Purpose: The sodium (^{23}Na) ion concentration is fundamentally connected to tissue physiology[1]. In chronical and acute myocardial infarction the vital ^{23}Na concentration gradient between intracellular (10-15mM) and extracellular (145mM) sodium is altered and infarcted regions present an increased sodium concentration[2,3]. However, cardiac ^{23}Na MRI is challenging even at ultra-high magnetic field strength ($B_0 \geq 7T$). In addition to low spatial resolution, fast relaxation times as well as respiratory and cardiac motion, inhomogeneities resulting from the B_0 and B_1 field can influence the accuracy of quantitative ^{23}Na MRI. In this study, B_0 and B_1 field maps were generated to correct phantom and in vivo data.

Methods: Phantom and in vivo data were acquired on a 7T whole-body system (MAGNETOM, Siemens Healthineers, Erlangen, Germany) with an oval-shaped birdcage coil[4]. A density-adapted 3D radial sampling[5] scheme and a golden angle[6] distribution was used with TR = 21ms, flip angle 61°, nominal spatial resolution $(6mm)^3$, readout duration TRO =2.7ms, pulse length = 1.8ms, TE1 = 0.95ms and TE2 = 6ms. Cardiac activity was recorded simultaneously with an ECG gating device.

B_0 field maps were generated through the phase difference of the two images with TE1 and TE2. A nominal spatial resolution of $(10mm)^3$ was used.
To produce B_1^+ field maps, the double angle method (DAM[7]) was applied. Two images with flip angles of 45° and 90° were acquired. To reduce T1 weighting, TRs of 100ms and 150ms were chosen for the 45° and 90° images, respectively. Further parameters were: nominal resolution $(10mm)^3$, TE=1.55ms, TRO = 5ms, pulse length = 3ms. The receive sensitivity distribution B_1^- was estimated from the homogenous phantom image with flip angle 45° and the flip angle map. In the phantom measurements it was applied to an image with flip angle of 61°.

Each data set was reconstructed with a non-uniform Fast Fourier Transform using a Hamming filter. Data sets for B_0 and B_1 maps were interpolated and Gauss filtered with σ=12mm. With a registered binary mask based on ^{1}H images with a resolution of $0.6x0.6x1.4mm^3$ (c.f. Figure 4), the influence of B_0 and B_1 correction was measured. As this mask was acquired in the exhaled state and during the diastole, projections of the ^{23}Na measurement were reordered to reconstruct the image in the diastole (Δt = 0.6s) by a retrospective cardiac gating method[3]. The influence of respiratory motion was reduced by self-gated ^{23}Na MRI[4] with separate reconstruction of the exhaled state.

Results: *Phantom:* The correction of B_0 inhomogeneity effects results in a vast improvement of image quality in the resolution phantom (c.f. Figure 1). The correction for B_1 effects with normalized B_1^+ and B_1^- field maps (c.f. Figure 2) lowers the coefficient of variation (CoV) of the homogenous phantom measurement from 8.8% to 0.1%.

In vivo: The correction of B_0 increases the signal within the heart muscle region of the binary mask by about 1%. In the heart region the relative flip angle accounts for 0.86 ± 0.08. For B_1 corrected images, the CoV for blood decreases by 18% and the signal in the heart muscle increases by 5.6%.

Discussion: The presented B_0 and B_1 correction markedly improves image quality of the phantom images.

The relative flip angle map B_1^+ and the receive sensitivity map B_1^- for phantom measurements show a different distribution. Thus, a correction of B_1 inhomogeneity based on reciprocity[8] is not a valid approach for our setup. Hence the correction of B_1^- inhomogeneities is estimated by using the normalized B_1^- map of the phantom.

Due to lower off resonances in the B_0 map of in vivo data compared to phantom measurements, the influence on the corrected image in particular the heart region is small. In contrast, the correction of B_1^+ and B_1^- inhomogeneity shows a larger effect. To further validate this method, simulations and measurements with different coil loadings are necessary to analyze the sensitivity of B_1^+ and B_1^- to coil loading.

Conclusion: This work demonstrates the handling of B_0 and B_1 inhomogeneities and analyzes its influence for ^{23}Na cardiac data. In particular, a valid method for the correction of B_1^- inhomogeneity effects might be a crucial point for future cardiac ^{23}Na MRI applications.

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References: 1. Madelin G et al. J Magn Reson Imaging. 2013, 38(3): 511-529; **2.** Constantinides CD et al. Magn Reson Med. 2001, 46: 1144-1151; **3.** Resetar A et al. Magn Reson Imaging. 2015, 33(9): 1091-1097; **4.** Platt T et al. Magn Reson Med. 2018, doi: 10.1002/mrm.27103; **5.** Nagel et al. Magn Reson Med 2009; (62):1565-1573 ; **6.** Chan, Rachel W et al. J Magn Reson Med. 2009; 61(2): 354-363; **7.** Insko EK et al. J Magn Reson Imaging. 1993, 103(1), 82-85; **8.** Hoult DI Concepts in Mag Res 2000, 12(4): 173-187;

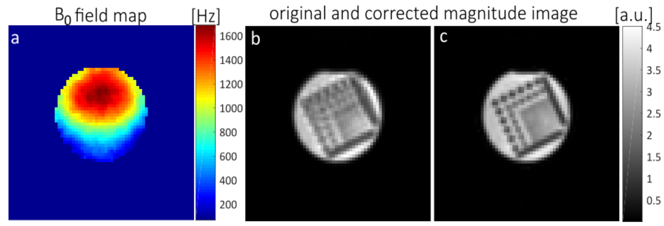

Figure 1: *(a) B_0 map of the resolution phantom generated from two images with TE1 = 0.95ms and TE2 = 6ms. (b) Original magnitude image with a nominal resolution of $(6mm)^3$.(c) B_0 corrected image of resolution phantom.*

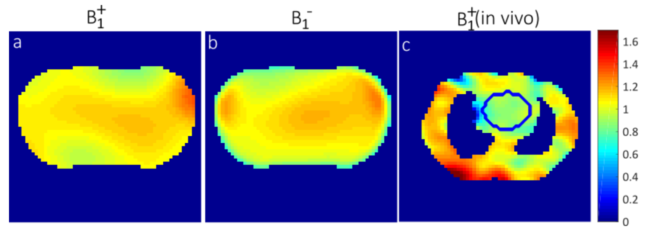

Figure 2: *Normalized B_1^+ maps of phantom (a) and in vivo (c) data generated with two images with α=45° and 2α=90° for DAM. (b) Normalized B_1^- map of phantom data. (a) and (b) demonstrate that a correction of B_1 inhomogeneity based on reciprocity [6] is not valid for our setup.*

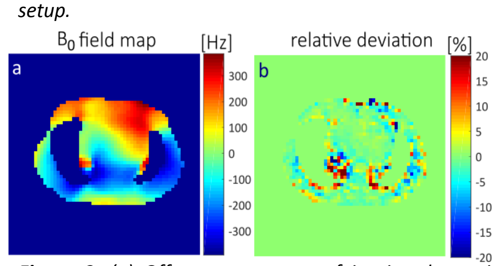

Figure 3: *(a) Off-resonance map of in vivo data with a nominal resolution of $(10mm)^3$.(b) Relative difference map between corrected and not corrected image.*

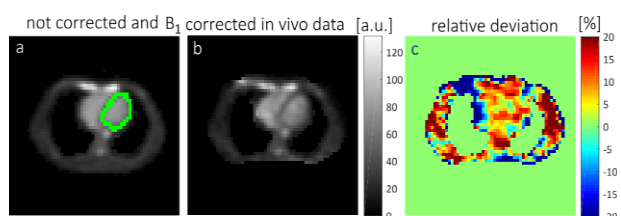

Figure 1: *(a) Cardiac ^{23}Na MR image at B_0=7T with binary mask based on ^{1}H. The acquisition time was 16min with 44000 projections. (b) Cardiac in vivo image corrected with B_1^+. (c) Relative deviation map of corrected (b) and not corrected (a) image*