High Resolution Quantitative ^{23}Na MRI of the Human Brain at 7T

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Target audience: Physicists an clinicians interested in the fields of quantitative X-nuclei MRI and accelerated acquisition

Purpose

Quantitative ^{23}Na MRI can provide valuable information about physiology in a wide range of pathologies[1,2]. However, it suffers from long acquisition times due to low in-vivo concentration and long repetition times to reduce relaxation effects. Here we propose an asymmetric 3D-radial acquisition scheme[3] in combination with a Dictionary Learning Compressed Sensing (DLCS) reconstruction[4] that allows for quantitative ^{23}Na MRI with high nominal isotropic resolution while keeping measurement time acceptable.

Methods

For the evaluation of the asymmetric sampling scheme and the following reconstruction, a density adapted 3D-radial[5] dataset consisting of 7000 projections was generated with a nominal isotropic resolution $(\Delta x)^3 = (1.7\text{mm})^3$ using a simulation tool and a ground truth with sodium concentrations for the human brain based on literature values[6]. The homogeneous sampling corresponds to ≈ 8% Nyquist. This 3D radial dataset was then further reduced by removing 2250 projections in the –z hemisphere to simulate a shorter acquisition and take advantage of k-space symmetry, leading to a sampling rate of ≈ 2% Nyquist in this region. The reduced dataset therefore consists of 4750 projections. The same homogeneous 7000 projections trajectory was used to acquire ^{23}Na MRI data from a healthy volunteer (female, 18y); this dataset was then asymmetrically reduced in the same manner. The measurement parameters were: TR/TE = 100ms/0.3ms, readout duration 10ms, 512 radial samples, flip angle α = 84° (Ernst angle), 3-fold averaging, and measurement time for the full/reduced dataset T_{acq} = 35 min/20 min. The volunteer measurement was performed on a 7T whole body scanner (Magnetom 7T, Siemens, Erlangen, Germany) with a ^{1}H/^{23}Na double resonant birdcage coil (Rapid Biomed GmbH, Rimpar, Germany).

The reconstruction of the full datasets was done with a Nonuniform Fast Fourier Transform (NUFFT), without and with Hamming filtering, the full and the reduced dataset were reconstructed with 3D Dictionary Learning Compressed Sensing (3D-DLCS) and the following reconstruction parameters: Block Size $B = 3^3$, data consistency weighting $\lambda = 0.9$, dictionary size $D = 500$. The reconstruction was initialized with a matrix of size 170×170×170 filled with zeroes and converged after 200 iterations (reconstruction time ≈ 5h on a standalone PC, Intel i7-2600, 16GB RAM). For the asymmetric dataset, the missing projections are estimated and updated in every iteration step, together with the new image estimate (par-DLCS).

Quantification was conducted by linear interpolation of the signal intensities in reference tubes (25/50/75/100/125/150 mM for simulated data and 51/102 mM in-vivo). Prior to quantification, B_1^+ and B_1^- correction was performed using the double angle method[7] for the volunteer measurement.

Results

The NUFFT reconstruction of the full simulated dataset and the par-DLCS reconstruction for the partial dataset are shown in figure 1, the same is shown for the in-vivo data in figure 2. The image quality is markedly improved for the par-DLCS reconstruction, even though the measurement time was reduced by 15 min. The estimates for the quantitative evaluation in a ROI placed in white matter are shown in table 1. The resulting values are overestimated for the NUFFT reconstructions and only slightly underestimated for the 3D-DLCS and par-DLCS reconstructions when compared to the ground truth (30 mM) of the simulation. For in-vivo data, however, the discrepancy is not as pronounced.

[mM]

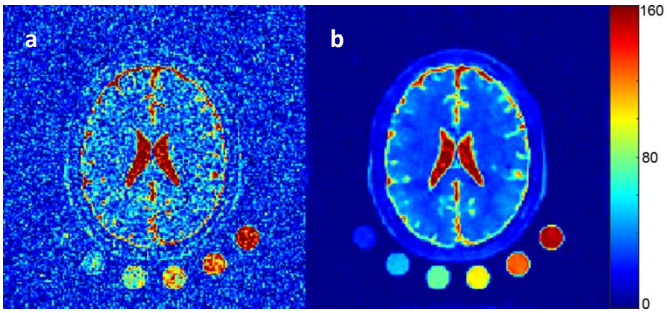

Figure 1: a) NUFFT reconstruction of the full simulated dataset containing 7000 projections with a nominal resolution of $(1.7\text{mm})^3$. b) par-DLCS reconstruction of the reduced asymmetric simulated dataset. The reference vials were used as concentration standards.

[mM]

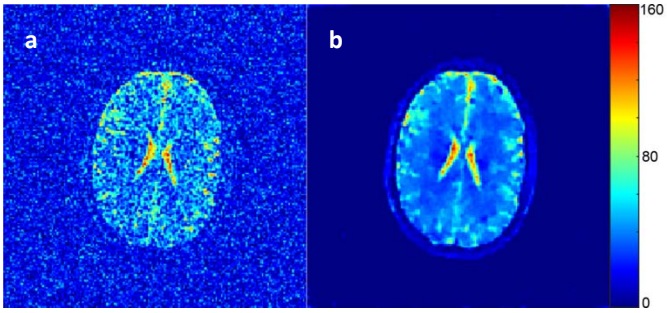

Figure 2: a) NUFFT reconstruction of the full in-vivo dataset containing 7000 projections with a nominal resolution of $(1.7\text{mm})^3$. Measurement time: 35 min

b) par-DLCS reconstruction of the reduced asymmetric in-vivo dataset. Quantification was done using reference vials not visible in the displayed slice. Measurement time: 20 min.

Table 1: Estimates for the ^{23}Na concentration in ROIs placed in white matter for simulated and in-vivo data. Reconstructions for the full datasets were done with NUFFT, without and with hamming filter, as well as with 3D-DLCS. The reduced datasets were reconstructed with par-DLCS. The ground truth for simulated data was 30 mM

^{23}Na concentration in WM [mM]

	NUFFT	NUFFT filt.	3D-DLCS	par-DLCS
Simulation	36.1 ± 19.0	36.1 ± 6.4	28.5 ± 2.1	29.3 ± 2.2
In-vivo	32.8 ± 12.6	32.4 ± 4.6	32.6 ± 1.5	30.7 ± 1.5

Discussion & Conclusion

The combination of asymmetrical sampling and Compressed Sensing based iterative reconstruction enables quantitative ^{23}Na MRI with a nominal resolution below $(2\text{mm})^3$ within acquisition times close to 20 min. This could be of interest especially for the recovery of small lesions, as well as to get a better delineation of heterogeneous structures in larger solid tumors.

References: [1] Madelin et al., Prog Nucl Magn Reson Spectrosc. 2014 79:14-47. [2] Thulborn et al., Neuroimage 2016 doi: 10.1016/j.neuroimage.2016.11.056 [3] Behl et al., Proc. ISMRM. 2016:3975 [4] Behl et al., Magn Reson Med. 2016 75:1605-16 [5] Nagel et al., Magn Reson Med. 2009 62:1565-73 [6] Lommen et al.: Proc. ISMRM 2017:5628 [7] Insko et al. J Magn Reson Imaging. 1993, 103:82-85