# CG-SENSE reconstruction for 30-channel $^{23}$Na MRI data

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## Target audience

Scientists interested in reconstruction techniques for non-proton MRI data.

## Purpose

In medical imaging, Sodium ($^{23}$Na) MRI provides physiological information which can be of interest for a variety of pathologies[1]. The low SNR due to the NMR sensitivity and in vivo concentration, as well as the fast transverse relaxation make $^{23}$Na MRI a challenging task. Using ultra-high field MR systems and ultra-short echo time sequences allows $^{23}$Na MRI at resolutions of a few millimeters within acceptable measurement times[2]. Parallel-imaging reduces the acquisition times and allows a more efficient coverage of k-space trajectories.
Spatial encoding information, such as nonhomogeneous sensitivity maps of multi-coil phased arrays, enables a reconstruction of the image with reduced artifacts[3]. The aim of this work is the reconstruction of radially undersampled 3D data recorded with a 30-channel array using a Non-Linear Conjugate Gradient Sensitivity Encoding (CG SENSE) method. This method is evaluated on data from a resolution phantom and on in vivo $^{23}$Na-data of a healthy volunteer.

## Methods

The CG SENSE method minimizes the following cost function:

$$\arg\min_{\mathbf{m}} \|\mathbf{FCm} - \mathbf{y}\|_2^2 + \lambda \|\boldsymbol{\psi}\, \mathbf{m}\|_1 ,$$

where **y** are the k-space data, **F** is a Nonuniform Fast Fourier Transform (NUFFT)[4], **C** are the 30 sensitivity maps (1 for every single-coil array of the 30-channel multi-coil arrays), and **m** is the reconstructed image. $\boldsymbol{\psi}$ is an optional sparsifying transform operator and $\boldsymbol{\lambda}$ is a regularization tuning constant which is set to zero in this work. To compute the 30 sensitivity maps every single-coil image is reconstructed with a 3D Gaussian filter ($\sigma = 5$) and divided by the sum-of-squares (SOS) combined image. The cost function is solved iteratively using the CG algorithm implemented by Lustig et al.[5].
The reconstruction is initialized with an image matrix of zeroes (100x100x100 for the resolution phantom and 128x128x128 for the in vivo data). The algorithm iterates 250 times and does a conjugate gradient reset every 50 iteration steps to improve its convergence.

The $^{23}$Na-data are acquired using a density-adapted 3D radial projection pulse sequence[6] on a 7T whole body MR system (Magnetom 7 T, Siemens Healthcare, Erlangen, Germany). A double-resonant 30-channel sodium head array volume coil (Rapid Biomedical GmbH, Rimpar, Germany) ($^1$H transmit/receive quadrature volume coil, $^{23}$Na transmit quadrature volume coil, $^{23}$Na receive array with 30 channels) was used to measure a resolution phantom (0.9% saline solution) and a healthy volunteer. We measured the phantom and the healthy volunteer with the same acquisition parameters ((1): 3mm isotropic, 15000 projections, TE/TR=0.35ms/30ms, α=53°, TA=7.5min, Nyquist sampling rate=15%), additionally the volunteer with a higher undersampling ratio ((2): 3mm isotropic, 7000 projections, TE/TR=0.35ms/30ms, α=53°, TA=3.5min, Nyquist sampling rate=7%).
The resolution phantom data were reconstructed using the CG SENSE algorithm for the first 2 channels and for 30 channels. The two in vivo data sets were reconstructed with both CG-SENSE and SOS.

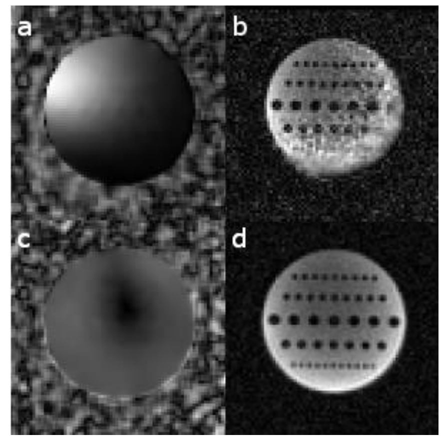


**Fig. 1:** Phantom $^{23}$Na–data, a: averaged sensitivity map of channels 1&2, b: CG SENSE reconstruction of channels 1&2, c: averaged sensitivity map of 30 channels, d: CG SENSE reconstruction of 30 channels.

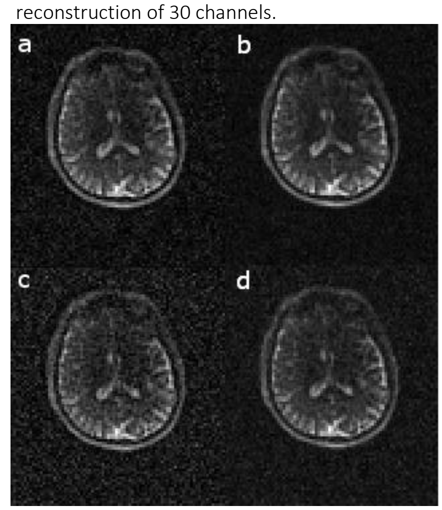


**Fig. 2**: In-vivo $^{23}$Na –data (30 channels), a: CG SENSE reconstruction, acquisition (1), b: SOS reconstruction, acquisition (1), c: CG SENSE reconstruction, acquisition (2), d: SOS reconstruction, acquisition (2).

## Results

Figure 1 shows the reconstructed sensitivity maps of the first 2 channels as well as 30 channels (figure 1a and 1c) and the corresponding reconstructed images using the CG SENSE algorithm (figure 1b and 1d) of the resolution phantom. The CG SENSE reconstruction for 2 channels needs 1h while the one for 30 channels needs 14-21h on a standalone PC (CPU: Intel Xeon E5-1620 v4, RAM: 64GB). Regions of small values in sensitivity maps correspond to blurry regions in the reconstructed images.
In figure 2, the 7-fold and 14-fold undersampled $^{23}$Na in vivo data are reconstructed with CG SENSE and a SOS combination (figure 2). The 7-fold undersampled CG SENSE reconstruction needs 19h and the 14-fold undersampled one needs 13h.
There is no significant difference between CG SENSE reconstructed and SOS combined images. Background noise remains present in CG SENSE reconstructed images, but there is a trend towards better delineation of small structures.

## Discussion & Conclusion

3D radial parallel-imaging of $^{23}$Na can reduce acquisition times. The undersampled $^{23}$Na-data are reconstructed using a CG SENSE algorithm. Fine structures are resolvable, but noise is a present disturbing factor. Without any regularization, there is no significant difference between CG SENSE reconstructed and SOS combined images. Including a regularization, such as a Tikhonov regularization or a sparsifying total variation, we expect the reconstructed images to improve immensely. Even if k-space is highly undersampled, incoherent undersampling artifacts could be strongly reduced[7].

## References

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