# Anatomically constrained magnetic resonance inverse imaging for human brain

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**Target audience**

The results presented in this work are of interest to researchers interested in the parallel imaging reconstruction and methodology to reveal the cortical and subcortical activation using high spatial and temporal resolution functional MRI.

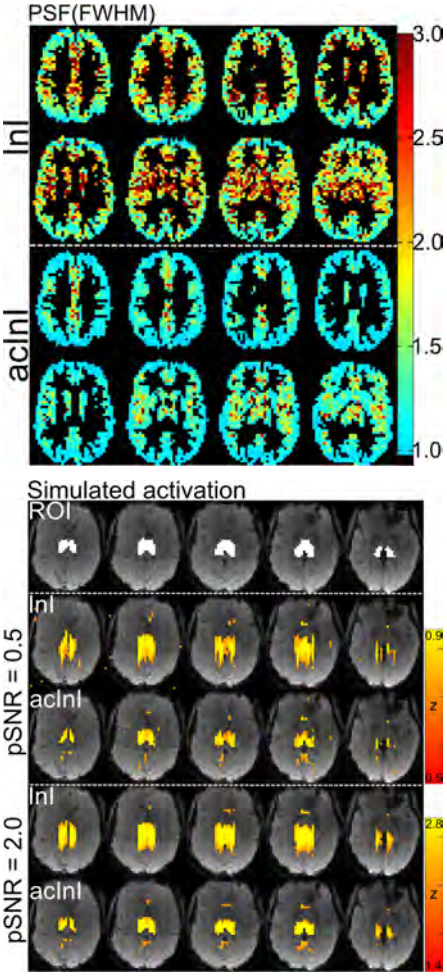
**Purpose**

MR inverse imaging (InI)[1] is a variant of parallel MRI (pMRI) seeking the maximal temporal acceleration: using highly parallel detection, dynamic images with the associated statistical maps can be obtained in 100 ms at 3T using a 32-channel coil array with whole head coverage and approximately 5 mm spatial resolution at cortex. Mathematically, InI reconstruction is similar to the under-determined inverse problem in magnetoencephalography (MEG) source localization[2]. Previously, it has been suggested that anatomical information can be incorporated in MEG source localization in order to improve the localization accuracy[3]. Here, we analogously use the anatomical information, specifically, the white/gray matter boundary, as the *a priori* information in InI reconstruction. Using simulations based on empirical measurements, we demonstrate that this anatomically constrained MR InI (acInI) reconstruction can reduce the bias and improve the spatial resolution in InI reconstruction.

**Methods**

A volumetric InI reference scan (multi-shot echo-planar imaging) of a human head was acquired on a 3T MRI (Skyra, Siemens Medical Solutions, Erlangen, Germany) with a 32 RF-channel head coil array (TR/TE = 100/30 ms, flip angle = 30°, bandwidth = 2520 Hz/pixel, image matrix = 64x64x64, FOV = 256x256x256 mm). The forward operator $\mathbf{A}$, which describes the linear mapping between a volumetric image to be reconstructed $\mathbf{x}$ and the accelerated InI measurement $\mathbf{y}$, was constructed from all channels of this reference scan. Mathematically, $\mathbf{y} = \mathbf{A}\mathbf{x} + \boldsymbol{\varepsilon}$, where $\boldsymbol{\varepsilon}$ denotes the residual error. We simulated the accelerated InI measurement $\mathbf{y_p}$ of a point source by using an impulse function as $\mathbf{x_p}$. We also acquired an anatomical images from the same participant using a *T1*-weighted sequence (MPRAGE[4]; TR/TE/TI = 2,530/3.49/1100 ms, flip angle = 7°, image matrix = 224×256x192, FOV = 224×256x192 mm). These images were processed by Freesurfer[5] to delineate the gray/white matter boundary. We down-sampled and registered this high spatial resolution gray/white matter boundary to the low spatial resolution reference scan, and used the Otsu's method[6] to binarize the gray/white matter boundary. The anatomical constraint was implemented as a diagonal source covariance matrix $\mathbf{R}$, whose diagonal entries, overlapped with gray matter, were set to 1 and other entries were set to zero. The acInI reconstruction is $\mathbf{x_p} = \mathbf{R}\mathbf{A}^{\mathbf{H}}(\mathbf{A}\mathbf{R}\mathbf{A}^{\boldsymbol{H}})^{-1}\mathbf{y_p}$. The spatial resolution was quantified by calculating the full-width-half-maximum (FWHM) of the point spread function (PSF)[7] across the cortical and subcortical areas. We also simulated the accelerated InI measurements with activation at the thalamus with peak SNR (pSNR) of 0.5 and 2.0. Reconstructions with and without anatomical constraint were calculated respectively. Results were transformed to *z* statistics and overlaid on 2D brain slices.

**Results**




The upper panel shows the spatial distribution of the FWHM of the PSF using InI and acInI. The spatial resolution of acInI was higher and more uniform than InI: the averages and standard deviations of the FWHM of the PSF were 1.9±1.3 and 1.2±0.7 pixels for InI and acInI, respectively. The lower panel shows the ROI and the *z* statistics of reconstructed activation from InI and acInI at the pSNR = 0.5 and 2.0. The white region indicates the ROI of the thalamus. The reconstructed results at the right panel suggest that acInI has better source localization accuracy than InI at the thalamus.

**Discussion**

Our simulation results suggested that, compared to the single projection InI reconstruction, acInI using the gray matter region delineated by high spatial resolution anatomical MRI as the *prior* information can improve the spatial resolution in the reconstruction.

In acInI reconstruction, we constrained the source to be located at the cortical and subcortical areas and omit the possibility of BOLD activation at the white matter[8]. However, the blood volume and flow are lower in white matter than that in gray matter[9], and also the BOLD signal is associated with the post-synaptic potentials[10] in gray matter. In this sense, acInI is still feasible to most of the functional and cognitive tasks in human brain.

**Conclusion**

In this report, we proposed the anatomically constrained InI reconstruction in order to mitigate the source localization uncertainty. With the better spatial resolution across the whole brain and keeps the fast temporal resolution at the same time, it is promising to probe cortical/subcortical activation in empirical data using acInI.

**References**

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