Visualization of the Subthalamic Nuclei using High-Resolution Susceptibility Mapping at 7T

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Introduction:

One important treatment for Parkinson's disease (PD) is electrical stimulation of the subthalamic nucleus (STN) [1]. Direct visualization of the STN for precise electrode positioning remains an issue, because this structure is relatively small and hard to distinguish from the adjacent substantia nigra (SN) [2]. A recent study used the high contrast of phase images to visualize the STN [3]. Unfortunately, phase images suffer from misleading non-local effects [4]. Here, we acquired high-resolution phase images at 7T, from which we calculated susceptibility maps that gave precise delineation of the STN while completely avoiding non-local effects.

Methods:

Phase images show the effects of a field perturbation $B_{dz}(\mathbf{r})$ due to a susceptibility distribution $\chi(\mathbf{r})$ in the presence of a field $B_0\hat{\mathbf{z}}$. The susceptibility distribution can be simply calculated in the Fourier domain using $\chi(\mathbf{r}) = \mathrm{FT}^{-1}\left(-3\cdot\widetilde{B}_{dz}(\mathbf{k})/B_0\cdot C^{-1}(\mathbf{k})\right)$ (equation 1), where "~" denotes the 3D Fourier transform (FT) and $C(\mathbf{k})$ is the FT of the convolution kernel, expressed as $C(\mathbf{k}) = 3k_z^2/|\mathbf{k}|^2 - 1.$ Unfortunately, on the magic angle cone the computed susceptibility tends to infinity, because the convolution kernel here passes through zero. However, a simple appropriate thresholding of the convolution kernel has been shown to solve the inversion problem [5].

8 young healthy subjects (22-28 years, 3 female), who gave informed consent, were examined on a whole body 7T scanner (MAGNETOM, Siemens Medical Solutions, Erlangen, Germany) using a 24 channel phased array coil (Nova Medical). The study was approved by the local ethics committee. For imaging a 3D spoiled gradient multiecho sequence (TR=40 ms; TE=11.22/21.41/31.59 ms; bw=150 Hz/pixel; voxel=0.5x0.5x0.6mm³) was used.

The phase data were unwrapped using PhUN [6]. Only the region around the STN and SN was analyzed. The rest of the brain was masked out with an ellipsoidal mask. A 2nd order polynomial fit to the unwrapped data was subtracted from the unwrapped data to obtain high-pass filtered phase data. The filtered phase data were divided by $\gamma B_0 TE$ to convert the field-shift to units of ppm. The data were resampled to 0.5 mm isotropic resolution. The susceptibility was then calculated using equation 1. Voxels with $C(\mathbf{k})$< |0.25| were omitted [5] before the inverse Fourier transform.

Results and discussion:

Figure 1 shows one slice of a magnitude image and the ellipsoidal mask used for post-processing. Figure 2 shows the magnitude image, filtered phase image, and the calculated susceptibility map for the masked region, displaying the SN and the STN. The susceptibility map completely avoids the non-local effects from the phase images and shows a clear distinction between the SN and the STN, especially in the coronal and sagittal view. Their susceptibilities are quantitatively different (0.06±0.02 ppm and 0.1±0.02 ppm for the STN and SN, respectively), and a dividing septum can typically be discerned. Susceptibility mapping based on high resolution phase images can localize the STN much better than phase and/or magnitude images.

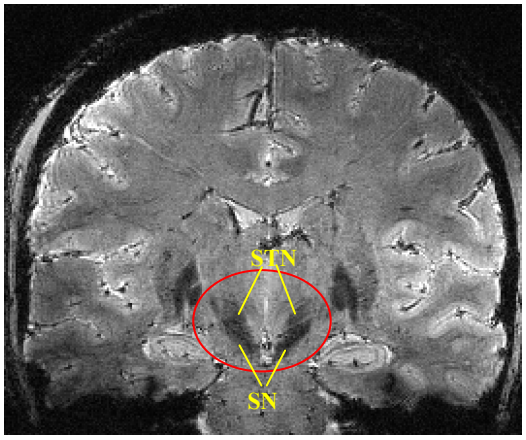

Figure1: Magnitude image and the ellipsoid mask, which was used for post-processing.

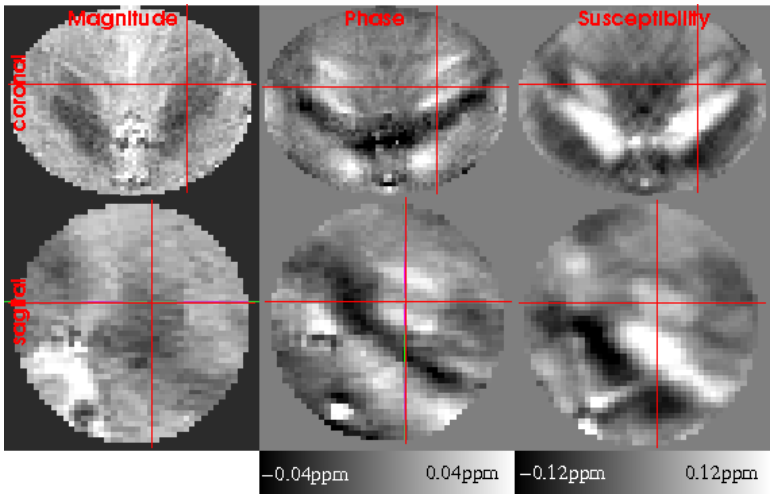

Figure2: The magnitude (left column), filtered phase (middle column), and the susceptibility map (right coulumn) of a single subject. Displayed are coronal (first row) and sagittal (bottom row) view. Note the non-local effects in phase images which are avoided by calculating the susceptibility maps.

References:

[1] Wichmann et al. Neuron 52:197-204 (2006); [2] Schaltenbrand and Wahren. Thieme (1977); [3] Vertinsky et al. AJNR 30:1717-1724 (2009); [4] Schäfer et al. NeuroImage 48:126-137 (2009); [5] Wharton et al. Proc ISMRM 17:463 (2009); [6] Witoszynskyj et al. Med Image Anal. 13:257-68 (2009)