Susceptibility Mapping of the Substantia Nigra in Parkinson Patients at 7T

A. Schäfer[1], D. V. Ott[1], A. Focke[2], J. Schwarz[2], R. Turner[1], and S. A. Kotz[1]
[1]Max-Planck-Institute for Human Cognitive and Brain Sciences, Leipzig, Germany, [2]University Hospital Leipzig, Leipzig, Germany

Introduction:

Parkinson's disease (PD) is characterized by the degeneration of dopaminergic neurons in the substantia nigra (SN). Here, oxygen radicals are produced excessively. The presence of these radicals leads to neuronal cell death. MR images of the SN show different transverse relaxation times in PD patients. This supports the pathological finding of increased iron content in the SN of these individuals [1]. A recent study used phase information to image iron concentration in the brain [2]. This is a promising approach because of the direct relationship between susceptibility and measured field-shift. However, the use of phase images may lead to further issues due to the non-local effects of the measured field-shift [3]. Here, we calculated susceptibility maps from phase image data, which completely avoid these non-local effects and thus provide a voxel-specific index of iron concentration.

Methods:

Theory:

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 $B_0\hat{\mathbf{z}}$. This distribution can be calculated using the simple local expression $\widetilde{B}_{dz}(\mathbf{k}) = -B_0/3 \cdot \widetilde{\chi}(\mathbf{k}) \cdot C(\mathbf{k})$ in the Fourier domain, where "~" denotes the 3D Fourier transform (FT) and $C(\mathbf{k})$ is the FT of the convolution kernel, expressed as $C(\mathbf{k}) = 3k_z^2/|\mathbf{k}|^2 - 1$. This leads to an apparently simple expression for the susceptibility distribution: $\chi(\mathbf{r}) = \mathrm{FT}^{-1}\left(-3 \cdot \widetilde{B}_{dz}(\mathbf{k})/B_0 \cdot C^{-1}(\mathbf{k})\right)$ (equation 1). Note that values of the convolution kernel lie in the range of -1 to 2. Unfortunately the convolution kernel passes through zero on the magic angle cone, which means χ here tends to infinity. To solve the inversion problem one can measure the field perturbation at different head angles [4;5] or simply threshold the convolution kernel [5]. We chose the thresholding option, since a patient population was involved and thus head angulation was not feasible.

Measurements:

6 patients (clinically diagnosed PD, not medicated; 55-77 years of age, 1 female) and 7 healthy controls (22-30 years, 4 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=9.76/19.19/28.62 ms; bw=150 Hz/pixel; voxel=0.6x0.6x0.8mm³) was used.

Postprocessing:

The phase data were unwrapped using PhUN [6]. Only the region around the red nuclei and SN was analyzed, the rest of the brain being 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 0.6 mm isotropic resolution. The susceptibility was then calculated using equation 1. Voxels with $C(\mathbf{k}) < |0.25|$ were omitted before the inverse Fourier transform.

Results and discussion:

All susceptibility maps were of good quality. Figure 1 shows the magnitude image, filtered phase image, and the calculated susceptibility map for one patient. ROI analysis yields a significant difference in susceptibility values in the SN between patients (0.15±0.05ppm) and controls (0.10±0.01ppm). The SN in patients is thus more paramagnetic compared to controls, probably due to increased iron content. Furthermore, the susceptibility values differ more in patients compared to controls as reflected in the standard deviation across subjects.

Rotating the head to avoid dividing by zero at the magic angle cone is impracticable for patient studies [4]. It is now shown that reasonable susceptibility maps of patients can be obtained even with one measurement, simply by thresholding the k-space filter. This opens the door to study of iron concentration in Parkinson's patients, and hopefully early-stage diagnosis of Parkinson's disease. Further work will include an age-matched control group.

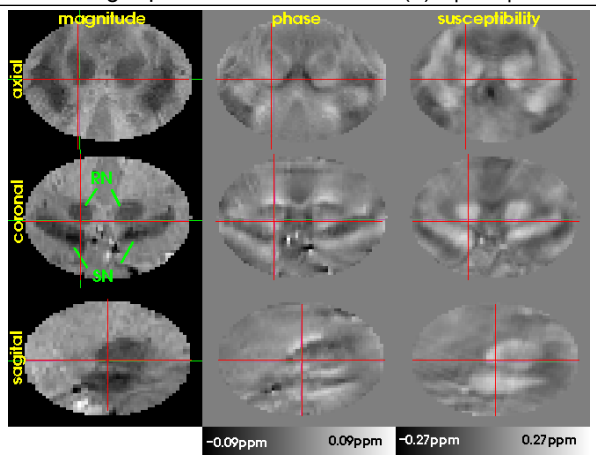

Figure1: The magnitude (left), filtered phase (middle) and the susceptibility map of one patient. Displayed are the axial (top), coronal (middle) and sagittal (bottom) view. Note the non-local effects in phase images, which are avoided by calculating the susceptibility maps.

References:

[1] Gorell et al. Neurology 45:1138-1143 (1995); [2] Yao et al. NeuroImage 44:1259-1266 (2009); [3] Schäfer et al. NeuroImage 48:126-137 (2009); [4] Liu et al. MRM 61:196-204 (2008); [5] Wharton et al. Proc ISMRM 17:463 (2009); [6] Witoszynskyj et al. Med Image Anal. 13:257-68 (2009)