Deconvolution and QSI of Simulated Phase Images of the Human Brain: Applications to assess Susceptibility

G. Grabner[1,2], S. Trattnig[1], and M. Barth[2]

[1]Department of Radiology, Medical University of Vienna, Vienna, Austria, [2]Donders Institute for Brain, Cognition and Behaviour, Radboud University Nijmegen, Nijmegen, Netherlands

Introduction: MR phase images reflect the magnetic susceptibility of tissues but the phase image is a convolution of the susceptibility map with the typical pattern of magnetic dipole [1]. This leads to very complex spatial patterns of the phase for example in the human brain where the different tissue types (GM and WM) as well as different structures (deep brain nuclei) have largely differing susceptibility. Using SWI the MR phase information can be measured very accurately and with high resolution. The challenge is to estimate the underlying tissue susceptibilities. One possibility is the deconvolution of the phase using a dipolar kernel, another one recently proposed tissue type ROIs to directly quantify magnetic susceptibility (QSI) [3]. Here we wanted to assess how accurate these methods are able to estimate the underlying properties using a realistic simulated phase model of the human brain.

Material and Methods:

In order to evaluate the effect of filtered deconvolution, an artificial 3D susceptibility map of a human brain which included gray matter (GM), white matter (WM), the putamen (PUT), the globus pallidus (GP), the red nuclei (RN) and the substantia nigra (SN) was created. Basis for this susceptibility map were two non-linear models – a T1-weighted and a phase model – both models were created from 32 subject data-sets [4]. The classification in GW and WM was done on the basis of the T1-weighted model; all other structures were manually traced on the phase model and superimposed to the GM/WM classification. The input values for the model for the different structures were taken form [1] which were; GM = -0.161; WM = 0.029; PUT = -0.2; GP = -0.089; RN = -0.21; SN = -0.233; these values are phase values in radians and reflect the tissue underlying susceptibility differences.

Phase maps were simulated by convoluting the artificial susceptibility map with a magnetic dipole using Eqn. 1. In order to calculate χ the simulated phase map (b,e) was deconvolved using Eqn. 2. In Eqn.1 and Eqn. 2, F represents the Fourier transform, χ the magnetic susceptibility and s a mask in frequency space. s, which is designed to address the noise amplification problem was set to 1 for F(dipole)>sd(abs(F(dipole))) and to zero for the remaining values. In the resulting deconvolved map the average χ - values for the PUT, the GP, the RN and the SN (ROIs were taken from the initial susceptibility map) were calculated and compared to the initial input values. χ - values were also calculated from the simulated phase data by using Quantitative Susceptibility Imaging (QSI) [3] and compared to the initial input values. In addition, the influence of the ROI size was assessed using erosion and dilation operations.

$$\text{Eqn. 1:}\quad phase = F^{-1}\left(F(\chi) * F(dipole)\right)$$

$$\text{Eqn. 2:}\quad \chi = F^{-1}\left(\frac{F(phase)}{F(dipole)} * s\right)$$

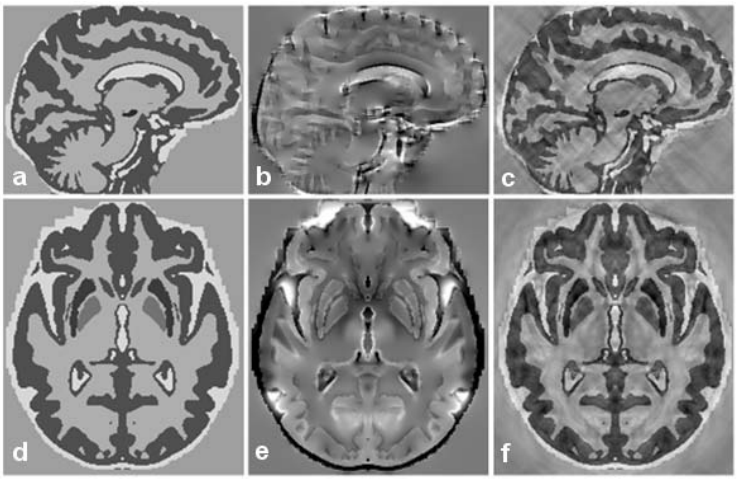

Fig. 1: Slices through the susceptibility map (a, d), the simulated phase (b, e) and the deconvolved-convolved susceptibility map (c, f). Note the artefacts resulting from masking in frequency space in (c, f) but also the better GM/WM contrast compared to (b, e) as well as the removed dipole effect in the area of the corpus callosum (c, f).

	Simulated χ (input)	Estimated χ (QSI)	Estimated χ (deconvolved data)
GP	-0.09	-0.09	-0.08
PUT	-0.20	-0.18	-0.14
RN	-0.21	-0.23	-0.20
SN	-0.23	-0.23	-0.17

Tab.1: Simulated and estimated χ values

Results: Fig. 1 shows the artificial three dimensional susceptibility map (a, d), the simulated phase (b, e), the deconvolved-convolved susceptibility map (c, f) and how masking in frequency space effects the performance of deconvolution. Phase values determined for the red nucleus (RN), the substantia nigra (SN), the putamen (PUT) and the globus pallidus (GP) are presented in Tab. 1. In Fig. 2 the importance of accurate ROI definition is demonstrated for the RN. As it can be seen the accurate estimation of susceptibility values critically depends on ROI size. Note the high standard deviation for a too large ROI.

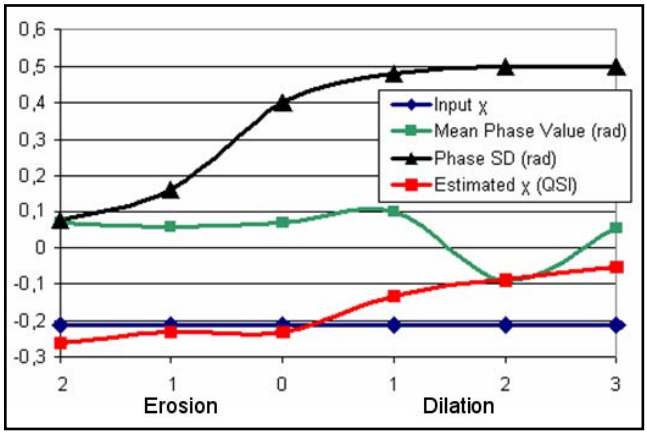

Fig. 2: Changes of estimated phase and χ values with respect to ROI erosion and dilation

Discussion and Conclusion: This work demonstrates the deconvolution of phase images and estimation of susceptibility values of specific structures using QSI on a simulated phase model resembling the human brain. Both methods show reasonable agreement with the true input value, but deconvolution is less accurate even in the absence of noise. This simulated phase model can also be used to simulate different influences such as noise and head position on the MR phase and susceptibility quantification.

References:

1) Pathak AP. et al. Neuroimage. 2008 Apr 15;40(3):1130-43.

2) Haacke EM. et al. J Magn Reson Imaging. 2007 Aug;26 (2):256-264.

3) de Rochefort L. et al. Magn Reson Med. 2008 Oct;60(4):1003-9.

4) G. Grabner et al. MICCAI 2006, volume II : 58–66