Quantitative susceptibility mapping of human brain by inverting local magnetic fields measured at multiple small angles

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Introduction: Quantitative susceptibility mapping of the brain would be valuable for assessing iron or calcium deposits associated with neurodegenerative and ischemic diseases [1], and for quantifying deoxygenated venous blood in fMRI [2]. Traditionally, susceptibility is characterized using T2*. Because T2* depends on spatial distribution in addition to tissue magnetic susceptibility, T2* characterization of susceptibility is not optimal.

Susceptibility can be quantitatively mapped by inverting the local magnetic field estimated from MR phase images. However, this inversion from field to susceptibility source is a challenging ill-posed problem. Recently, several methods were proposed to stabilize this inverse problem [3-8]. One such method, by calculating susceptibility through multiple orientation sampling [3], overcomes the problem by conditioning data acquisition, and has been validated as a robust and accurate approach *ex vivo*. In this study, we adapt this multiple orientation inversion to *in vivo* brain imaging using small angles with respect to B_0 allowed in a birdcage head coil.

Materials and Methods:

Data acquisition: Experiments were conducted at 1.5T (GE Signa EXCITE 14.0) using a 3D fast gradient echo sequence modified to acquire 7 TEs in one TR (TEs ranging from 4.4 ms to 47 ms with an equal TE spacing of 7.1 ms). Axial slices were acquired with FOV=22cm, matrix =220×220×32, *kz* direction is zero padded to make each voxel have an isotropic resolution of $1mm^3$, bandwidth=15.63×2kHz, TR=53ms and flip angle=30˚. Subjects (n=7, IRB approved) were instructed to rotate head in the coronal plane by bringing the ear to touch first the left and then the right shoulder typically rotating from -20˚ to +20˚. Data were also acquired in neutral position. In addition, a time of flight brain venogram was also acquired for reference using an arterial saturation pulse at the neck region.

Data processing: Normalized mutual information registration was conducted using the realignment toolkit Statistical Parametric Mapping to register the brain images from the three positions. A high pass filter (HPF) [9] was applied to the complex image data to remove the background field and the susceptibility effects from any air/tissue interfaces. The field map was subsequently estimated from the phase evolution across TEs. Susceptibility maps were calculated by inverting the dipole fields measured from multiple orientations [3], which is essentially a weighted least square fitting of the field map based on conjugate gradient. Susceptibility values of the venous blood were measured as the mean value inside the veins.

Results: A representative sagittal image shown in Fig. 1 displays cortical veins with positive contrast in the susceptibility image that are well-resolved from the surrounding tissues. Vein location on the susceptibility image matches the corresponding venogram. The mean susceptibility value measured in the cortical veins is 0.12ppm relative to surrounding tissues, suggesting an approximate 5% deoxygenation in the venous blood assuming fully deoxygenated blood has a susceptibility of 2.26 ppm [10].

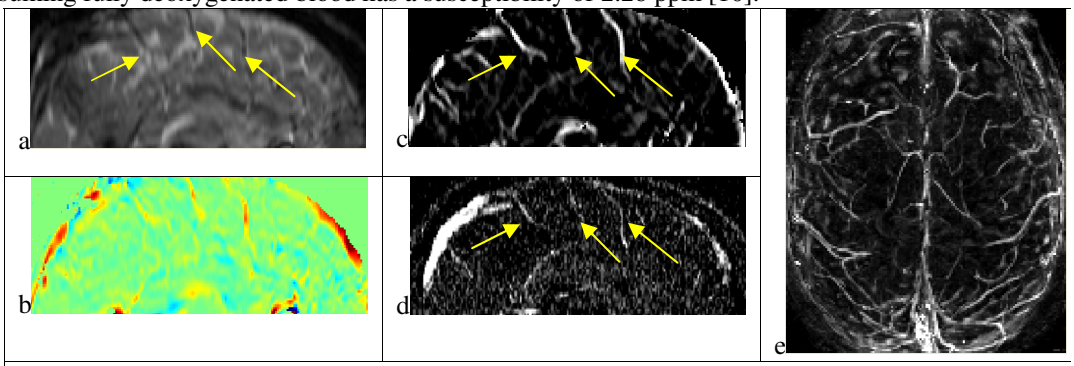

Fig.1. a) magnitude from GRE. Yellow arrows indicating cortical veins. b) field map, c) susceptibility map, d) venogram and e) axial MIP image of the susceptibility map

Discussion and conclusion: The oxygen consumption presented here (5%) is lower than a reported average value (25%) [11]. Possible explanations come from a broad standard deviation of the oxygen consumption [11]. HPF of the image data also washes out some dipole fields along with the background. In addition, limited resolution and registration ($1mm^3$) is likely to cause partial volume effect for detailed structures such as veins. To solve these issues, modeling the air/tissue interface instead of HPF and increasing spatial resolution can be applied. Despite the imperfections of the data processing, quantitative susceptibility images of the brain were successfully inverted using multiple small angle acquisitions. This may allow quantitative mapping of brain iron or calcium overload for assessing neurodegenerative or ischemic diseases and also enables quantification of blood oxygenation. Compared to the large rotations used in vitro and small animal imaging, the small angle pays a penalty in SNR. A noise reduction algorithm, such as Bayesian reconstruction using a piecewise smooth prior, may be used to improve SNR.

Ref: [1] Haacke et al., MRI: 23: 1-25. [2] Ogawa et al., MRM: 29: 205-210. [3] Liu et al., ISMRM 2008: 643. [4] de Rochefort et al., MRM: 60: 1003. [5] Kressler et al., ISMRM 2008: 1514. [6] Schäfer et al., ISMRM 2008: 641. [7] Shmueli et al., ISMRM 2008: 642. [8] Hammond et al., ISMRM 2008: 1512. [9] Wang et al., JMRI: 12: 661-670. [10] Weisskoff et al., MRM: 24: 375-383. [11] KEYS et al., AM J PHYS. 1938