Quantification of Blood Oxygen-level Dependent Signal Changes of Rat Brain by Using Quantitative Susceptibility Mapping

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Introduction Functional MRI (fMRI) based on blood-oxygen-level-dependent (BOLD) contrast has been widely used in investigating neural activity by detecting its association to the blood flow [1]. However, the accuracy of BOLD fMRI signals may be affected by several physical or physiological factors, such as B_0 inhomogeneity, diffusion effects and the hemodynamic mechanism of blood vessels. A recent MRI approach, referred to as quantitative susceptibility mapping (QSM), has been proposed to have the potential to quantify the susceptibility within tissues, which may be also capable of improving the measurement of oxygenation-dependent susceptibility changes. To understand the relationship between tissue oxygenation and resulting susceptibility changes, in this study, we aimed to employ QSM technique on rats with different oxygenation levels and investigate the susceptibility changes within different regions of the brain, including gray matter, white matter, capillary and vein. The potential of QSM on mapping fMRI was also investigated and discussed.

Materials and Methods MR experiments were performed on a Bruker 7T 70/30 Biospec scanner using a birdcage transmitter and four-channel phased array for signal acquisition. Three Spraque-Dawley rats were anesthetized with 2% Isoflurance. Additionally, these rats were breathing with the following two conditions, (a) 100% oxygen and (b) mixed gas, which consisted of 20% O_2, 5% CO_2 and 75% N_2, to simulate BOLD signal change in fMRI experiment. The condition (a) was performed with a 20-minute duration after condition (b) to ensure a complete gas exchange. The T2*-weighted images were acquired by 3-dimensional (3D) gradient-echo sequence with 1st flow compensation and following parameters, FOV = 3.8×2.63×1.64 cm^3, matrix size = 324×224×140, TR/ TE = 96.3/ 20 ms, FA = 20°, BW = 25 kHz and the total acquisition time of 50 minutes. The image reconstruction and QSM calculation were processed offline on MATLAB (MathWorks, MA, USA). To obtain susceptibility maps, firstly, all phase images were extracted from a four-channel raw dataset and combined by the complex summation [2]. Secondly, the wrapped phase was unwrapped using a path-based unwrapping method [3]. Afterwards, the background field was removed by SHARP (Sophisticated Harmonic Artifact Reduction on Phase data) and PDF (Projection onto Dipole Field) methods [4, 5]. Finally, the susceptibility maps were inversed from internal field maps by applying an optimized total variation regularization to eliminate noise propagation [6]. Four regions-of-interest (ROIs) were manually selected for following statistical comparison, including cortical gray matter, corpus callosum, capillaries and veins.

Results Fig. 1 shows the T2*-weighted images (Fig. 1A and 1B), internal field maps (Fig. 1C and 1D) and susceptibility maps (Fig. 1E and 1F) with 100% oxygen and mixed gas, suggesting that the susceptibility values increase considerably in several regions while the oxygenation concentration decreases from 100% to 20%. Fig. 2 shows the estimated susceptibility value of these two different oxygenation levels obtained from four ROIs, demonstrating that the susceptibility values increase 110% in capillary on cortex and 50% in vein (TRS). Fig. 3 shows the region-of-interest where we chose.

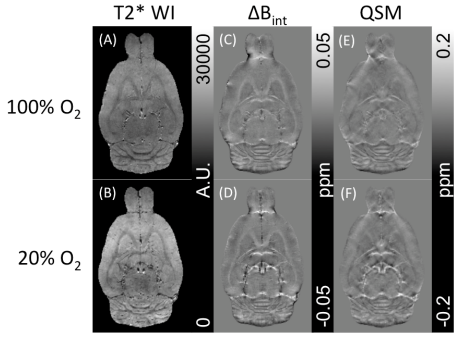

Fig 1. (A)(B) T2 weighted images, (C)(D) internal field maps and (E)(F) susceptibility maps of rat brain in two different blood oxygenation levels.*

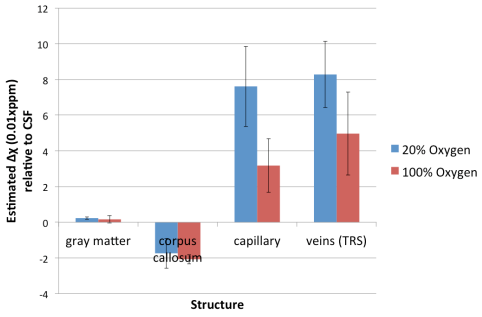

Fig 2. Estimated susceptibility values in four ROIs, including gray matter, corpus callosum, capillary in cortex and veins (TRS).

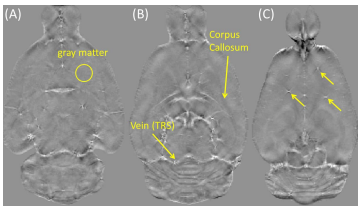

Fig 3. Region of interest. (A) gray matter (yellow circle), (B) corpus callosum and vein (TRS), and (C) capillary on cortex are indicated in yellow arrows.

Discussions & Conclusions In this study, our results showed that the susceptibility values changed considerably in capillaries and veins by comparing two different oxygenation levels, implying that the oxygenation changes may significantly affect the susceptibility measurement in the brain. By quantifying oxygenation-dependent susceptibility changes, QSM could be a potentially useful imaging tool to investigate the BOLD effects in a quantitative way. Future works may include increasing the oxygen concentration levels to investigate its association with susceptibility changes and developing adequate sequence to map the functional activation with quantitative susceptibility changes.

References [1] S. Ogawa et al., *MRM*, 1990; [2] K. Hammond et al., *NeuroImage*, 2008; [3] H. Abdul-Rahman et al., *Applied Optics*, 2007; [4] F. Schweser et al., *NeuroImage*, 2011; [5] T. Liu et al., *NMR in Biomedicine*, 2011; [6] M.-C. Hsieh et al., *ISMRM*, 2012.