Reproducibility of Quantitative Susceptibility Mapping (QSM) and R2* in the Human Brain

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Targets: MD and PhD interested in quantitative susceptibility mapping.

Purpose: Quantitative susceptibility mapping (QSM) is a method to generate a susceptibility map from phase images of GRE data. The method has been successfully used in quantifying iron, calcium, and gadolinium [1,2]. However, the procedure of reconstructing the susceptibility maps includes several data processing steps, which may result in noise and artifacts in the maps [3]. Thus, it is necessary to assess reproducibility of QSM. In this study, we explored the intra-scan reproducibility of QSM in the human brain. For comparison, the same data were used to generate a R_2^* map and the reproducibility of the two methods were compared. Additionally, respiration has shown an important source for artifacts in both QSM and R_2^*. So the effects of respiration on the reproducibility were tested.

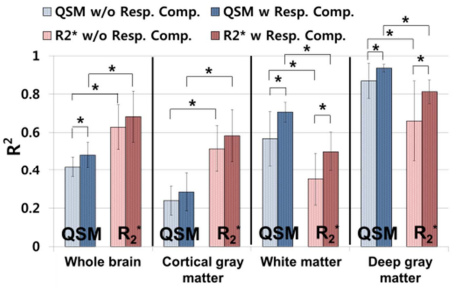

Figure 1. Respiration compensation

Methods: ***[Data acquisition]*** 3D multi-echo GRE data were acquired on five healthy subjects at 3T MRI (Siemens) using 32 channel coil. The scan parameters were as follows: resolution = 1.2 mm isotropic voxel, 80 slices, TR = 54 ms, TE = 9:7.8:48.1 ms, GRAPPA factor = 3, flip angle = 17°, and scan time = 6 min 4 s. The last echo was acquired as a B_0 navigation echo for respiration noise correction [4]. Each subject was scanned twice immediately. MPRAGE image was acquired at the end of the scan and was used for tissue segmentation. ***[Data processing]*** QSM images were reconstructed using PDF algorithm [2] for background removal and MEDI algorithm for dipole inversion [5]. Different regularization factors in the dipole inversion (λ = 50, 100, 300, 500, and 2000) were tested to investigate the changes in reproducibility (for respiration compensated data). For all other comparisons, QSM images were generated with a recommended λ value of 500. To generate a R_2^* map, the magnitude data were fitted using non-linear least squares mono-exponential fitting using trust region reflective algorithm. To verify the effects of the of respiration compensation on reproducibility, both QSM and R_2^* data were reconstructed with and without the navigator correction. To compare the effect of a voxel size on reproducibility, the respiration compensated data were reprocessed to generate a lower resolution (1.6 mm iso and 2.0 mm iso) by removing the edges of the k-space data. ***[Data analysis]*** After generating QSM and R_2^* maps, a voxel-wise correlation (R^2) of the two scan data was calculated in the whole brain, cortical gray matter, deep gray matter, and white matter. To generate each correlation, masks of each tissue type were obtained from the MPRAGE images (FSL). The deep gray matter mask that includes putamen, globus pallidus, and caudate nucleus areas was manually created. Paired t-test was performed to evalutae a statistical significant difference between the results.

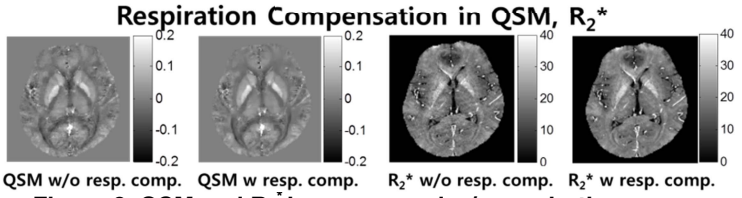

Figure 2. QSM and R_2^* images w and w/o respiration comp.

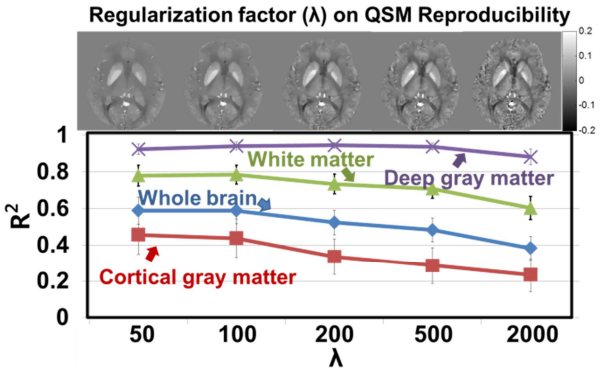

Figure 3. Effects of regularization factor

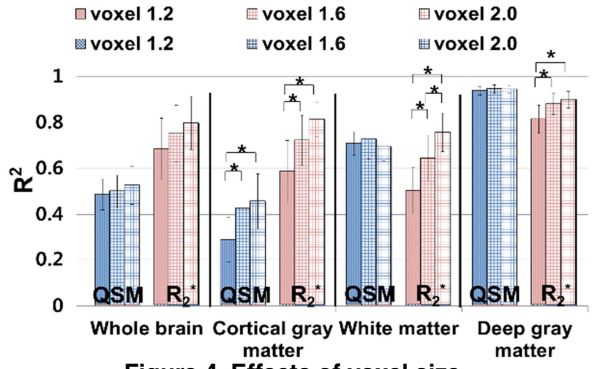

Figure 4. Effects of voxel size

Results: When respiration-induced artifacts were compensated, the reproducibility was improved in both QSM and R_2^* (Figures 1 and 2) demonstrating the important of respiration compensation. When the reproducibility of QSM and R_2^* is compared, QSM seems to show better results in the white matter and deep grey matter areas. However, these results are affected by the difference in the size point-spread-function (i.e. resolution; see discussion for details). When a regularization factor for QSM decreases (i.e. smoother images), overall R^2 increases (Fig. 3). This is likely from caused by the smoothing effects in smaller λs. Increasing voxel sizes generally improved reproducibility (Fig. 4). However, no change was observed in the white matter and deep gray matter of QSM (see discussion).

Discussion & Conclusion: This work summarizes the intra-scan reproducibility of QSM and R_2^* in various conditions. An interesting finding is that the QSM reproducibility in white matter and deep gray matter is not enhanced with increasing voxel sizes. This may be explained by the smoothing effects of the QSM inversion algorithm which creates a larger voxel size (locally varying point spread function) than a nominal voxel size (see QSM images in Figure 3). For this reason, the comparison between QSM and R_2^* reproducibility (Fig. 1) is not fair.

Ref: [1] Shmueli, MRM, 2009 [2] Liu, NMR Biomed, 2011 [3] Lin, AJNR Am J Neuroradiol, 2014 [4] Wen, MRM, 2014 [5] Liu, MRM, 2013