Echo-Planar Susceptibility Mapping

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Target audience: Researchers and clinicians interested in rapid quantitative susceptibility mapping in less than 10 seconds.

Purpose: Quantitative susceptibility mapping (QSM) is a valuable new approach for subcortical brain iron mapping [1,2]. However, acquisition times are typically on the order of 5-10 minutes, which is acceptable in dedicated studies but limits wider use in the clinic for standard brain exams due to the considerable time penalty. The aim is to develop and test an extremely rapid means (under 10 seconds) of acquiring whole brain QSM to study subcortical brain iron.

Methods: Echo-Planar Susceptibility Mapping (EPSM) was performed on 5 healthy volunteers (age 28 ± 4 yrs) using a standard 1.5 T. The whole brain acquisition was accomplished in 7 seconds using thin slice, single-shot 2D gradient echo EPI. The new method was compared to standard QSM using a flow-compensated, 3D gradient echo approach as used in standard susceptibility-weighted imaging (SWI). Analysis was performed by examining susceptibility values in iron-rich subcortical grey matter regions.

MRI acquisition: The EPSM method used a gradient echo EPI acquisition of 7 seconds (TE 40 ms, single shot with 128 echoes, 2 mm slice thickness, 60 axial slices, 128 x 128 matrix and in-plane voxel dimensions of 1.64 x 1.64 mm, 208 kHz bandwidth, 90˚ excitation, no parallel imaging or partial Fourier). No distortion correction was used. A standard 3D gradient echo SWI sequence was also performed with an acquisition 50 times longer at 6 min (TE 40 ms, TR 49 ms, 320 x 252 x 56 matrix, voxel dimensions interpolated from 0.72 x 0.81 x 2.44 mm to 0.72 x 0.72 x 1.9 mm, 15˚ excitation, parallel imaging R = 2 GRAPPA, and 1st order flow compensation in readout). An 8-element head coil was used for both sequences. The raw data was saved and moved offline for QSM reconstruction.

QSM reconstruction: The same reconstruction scheme was applied to all images of both sequences. Multi-channel complex images were first combined using an adaptive method [3]. Phase images were unwrapped using PRELUDE/FSL. A 3D first order polynomial fit was applied on the unwrapped phase to remove receiver coil phase offset. Background phase due to air/tissue susceptibility interfaces was removed using RESHARP [4], with a kernel radius of 5 mm and Tikhonov regularization of 10^{-3}. Lastly, susceptibility inversion was performed using the total variation technique [5,6] with regularization parameter of 5×10^{-4}.

QSM Measurements: EPSM images were interpolated and registered to the high resolution SWI-QSM (0.72 x 0.72 x 1.9 mm) using FLIRT/FSL. Bilateral, 2D regions-of-interest (ROIs) were manually drawn on the SWI-QSM images in iron-rich subcortical grey matter regions (Globus Pallidus, Putamen, Caudate Nucleus, Thalamus, Substantia Nigra, and Red Nucleus). The same ROIs were then overlayed on the registered EPSM images. Some of the ROIs were slightly adjusted for EPSM by translations only, to avoid partial volume and distortion effects. Mean susceptibility and standard deviation of each subcortical grey matter region from all subjects was reported, and 2-tailed t-tests were performed to compare group differences from two methods.

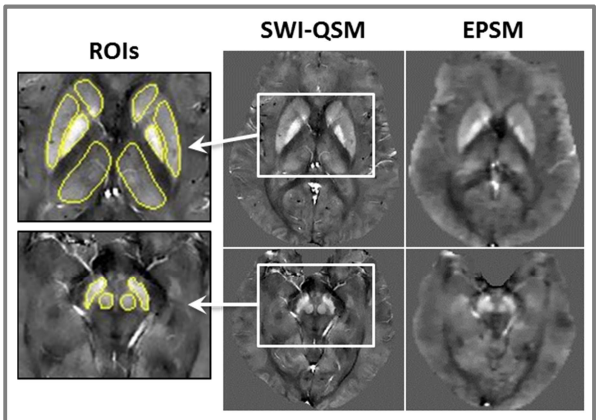

Fig 1: Axial slices of subcortical nuclei, left: ROIs, center: SWI-QSM and right: EPSM.

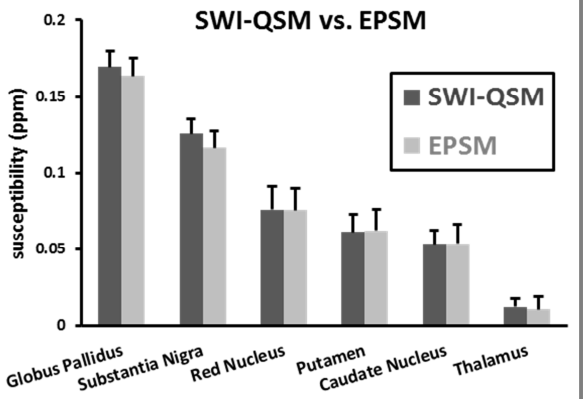

Fig 2: Mean susceptibilities of subcortical grey matter regions for both methods with no normalization.

Results: Figure 1 illustrates QSM images using both methods. The lower resolution EPSM appears blurry relative to the SWI-QSM, however it retains the distinctive hyperintense signal from iron rich nuclei, providing clear delineation from surrounding tissues and enabling ROIs to be easily drawn around the border of each subcortical region. The mean susceptibilities of subcortical grey matter regions measured across all 5 subjects are shown in Fig. 2 for both methods. Mean values for each region are similar for both methods. *P* values from the 2-tailed t-test comparing method difference showed no significant difference for any territory.

Discussion: EPSM produces similar susceptibility values to standard QSM acquired via a high resolution SWI sequence in iron-rich subcortical grey matter. Given the 7 second acquisition time, EPSM is attractive for adding to clinical protocols and research studies when there is insufficient time to perform standard QSM. This may enable increased study of subcortical brain iron in the clinic. For functional MRI studies that already use gradient echo EPI, EPSM requires zero additional scan time, enabling additional subcortical brain iron studies. Essential for EPSM is saving of the raw data or the unprocessed phase in addition to the default magnitude images.

Conclusion: EPSM can be performed about 50 times faster than standard QSM, enabling subcortical brain iron studies when time is limited.

References: [1] Liu et al. NeuroImage (2012) 59(3):2560-8. [2] Langkammer et al. Neuroimage (2012) 62(3):1593-9. [3] Walsh et al. MRM (2000) 43(5):682. [4] Sun and Wilman. MRM (2013) doi: 10.1002/mrm.24765. [5] Lustig et al. MRM (2007) 58(6):1182-95. [6] Wu et al. MRM (2012) 67(1):137-47.