Frequency-based multi-echo susceptibility weighted imaging

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INTRODUCTION

Susceptibility weighted imaging (SWI) is a neuroimaging technique for MR that derives contrast from susceptibility. By combining both magnitude and phase data of a gradient echo acquisition, SWI is made sensitive to venous blood as well as other field perturbers including blood products, iron, and calcium [1]. Recently, SWI based on multi-echo gradient echo acquisitions has been described, demonstrating improvements in image signal to noise ratio (SNR) of white matter as well as contrast to noise ratio (CNR) of veins and other structures [2,3]. The objectives of this study were (i) to report a new multi-echo, frequency-based SWI post-processing scheme, and (ii) to compare this scheme with two previously reported multi-echo SWI pipelines as well as conventional (single-echo) SWI.

METHODS

MRI Protocol. Ten healthy volunteers were scanned on a 3 T MR scanner with a 32-channel head coil. The protocol included 3D GRE (TE/TR = 20/30 ms, BW = 80 Hz/pixel) and multi-echo 3D GRE (TEs = 10, 17, 24, 31, 38, 45 ms, TR = 52 ms, BW = 160 Hz/pixel). Sequences were performed with the same resolution (0.5x0.5x1.0 mm^3) and with GRAPPA factor = 2. The single echo acquisition was flow compensated, as was the first echo of the multi-echo sequence.

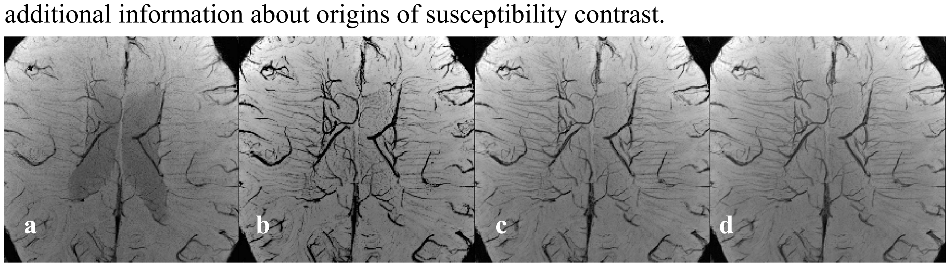
Post-processing. The single-echo data were processed according to [1]. Phase was high-pass filtered, a phase mask was generated and multiplied into the magnitude image 4 times. Multi-echo data were processed in three separate ways, described below.

(1) *Pre-average* scheme, modified from [2]. For a given slice, high-pass filtered phase was averaged over all TE's, as was magnitude. A phase mask was generated from the average phase and multiplied 4 times into the average magnitude.
(2) *Post-average* scheme, modified from [3]. For each echo, a SWI volume was created according to the conventional pipeline. All 6 SWI volumes were averaged to create a single volume.
(3) *Frequency-based* scheme. An average frequency volume was generated by averaging the [filtered phase/TE] from each echo. A frequency mask was created by scaling frequency to values between 0 and 1: values of frequency less than a cutoff value (-10 Hz was optimal) was set to 0 in the mask; values > 0 Hz were set to unity in the mask, and intermediate values, f, were scaled according to: $1/2 + 1/2\cos(\pi f/10\ \text{Hz})$. The mask was then multiplied into the average magnitude volume m times. Through simulation (data not presented here), the optimal value of m was found to be 15.

Analysis/Statistics. SNR was measured as the mean value in a region of interest (ROI) divided by the standard deviation in that ROI. CNR was measured as the difference in mean signals between two ROI's divided by the standard deviation in the larger ROI. Repeated-measures ANOVA and Tukey test were employed to assess statistical differences.

RESULTS & DISCUSSION

Shown in Fig. 1 are representative images at the level of the lateral ventricles from the four SWI methods compared. In all three multi-echo images (b-d), more veins are visible than in conventional SWI (a). However, veins appear with greatest contrast in the frequency-based SWI (b). Fractional increases of SNR or CNR (compared to single-echo SWI) in various structures are presented in Fig. 2. The starkest increase is for periventricular veins, where frequency-based SWI sees an increase in CNR of nearly 150% compared to single-echo SWI. It is noteworthy that very significant improvements in CNR of the optic radiations and globus pallidus (representative white matter tract and iron rich structure, respectively) are observed relative to other multi-echo SWI. While not described here, relaxometry could also be performed on the multi-echo data to generate quantitative maps of the apparent transverse relaxation rate, providing additional information about origins of susceptibility contrast.



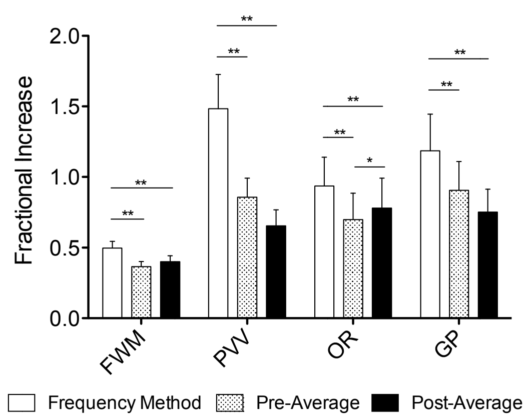


Fig 1 (left). Single echo SWI (a), and multi-echo SWI's: frequency-based (b), pre-average (c), and post-average schemes (d). (10 mm minimum intensity projections).
Fig. 2 (right). Mean increase in signal to noise in frontal white matter (FWM) and contrast to noise in paraventricular veins (PVV), optic radiations (OR), and globus pallidus (GP) relative to single echo SWI. ** = $p < 0.001$, * = $p < 0.05$.

CONCLUSION

Frequency-based multi-echo SWI shows very significant improvements in visibility of small veins, white matter tracts, and iron-rich structures compared to previously described multi-echo SWI post-processing schemes [2,3].

REFERENCES [1] Haacke et al. Am. J. Neuroradiol. 2009; 30:19-30. [2] Brainovich et al. Magn. Reson. Imaging 2009; 27:23-37. [3] Denk and Rauscher J. Magn. Reson. Imaging 2010; 31:185-191.