Optimization of Inter-Echo Variance Channel Combination Technique for Susceptibility Weighted Imaging at 3T and 7T

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TARGET AUDIENCE: Researchers and clinicians interested in vein visualization in brain**.**

INTRODUCTION: Susceptibility weighted imaging (SWI) is an established MR technique for visualization of veins in the brain. Because susceptibility affects the phase of the complex MR signal, the phase images are used to generate masks that are applied to the magnitude images to increase contrast between veins and surrounding tissues. When multi-channel acquisition is used a robust channel combination technique is required to prevent phase image corruption.[1] Recently, a channel combination technique, based on calculating the inter-echo variance (IEV), was introduced and shown to generate accurate local frequency (LFS) maps from multi-echo acquisitions.[2] In this study, we evaluate and optimize the application of the IEV technique to SWI in the brain at 3 and 7T.

METHODS: ***Imaging:*** Healthy volunteers were imaged at 7T and 3T using 16-channel and 32-channel head coils, respectively. Three-dimensional (3D) multi-echo gradient echo sequences were used (7T: 6 echoes, TR/TE/Echo spacing: 40/3.77/4.1 ms, matrix: 380 x 340 x 102; 3T: 4 echoes, TR/TE/Echo spacing: 42.5/13.0/3.88 ms, matrix: 384 x 384 x 32).

Channel combination and SWI generation: Channel combination was performed using the IEV technique for a set of filter kernel sizes. Briefly, IEV channel combination first unwraps the phase images,[3] applies a Gaussian filter with a kernel size σ, then calculates the inter-echo variance on a pixel-by-pixel basis and uses it as a weighting factor during channel combination. On an echo-by-echo basis, the IEV LFS maps are then converted into phase maps using a factor of $2\pi TE_i$, where TE_i is the i^{th} echo time. A standard approach[4] was used to generate the SWI at each echo. Lastly, the SWI images from each echo were averaged to increase SNR.[5]

***Optimization*:** The quality of the phase mask is greatly dependent on the filter kernel size used[5]. In this study we evaluated the effect of increasing σ from 0.001 to 0.13 in increments of 0.002. Furthermore, the effect of the number of slices used in the minimum intensity projection (mIP) was also evaluated, with mIPs generated from 3, 5, and 7 slices. Single slice images (*i.e.* without mIP, denoted as 1 slice) were also compared to the mIPs. For comparison, mIPs were also generated from the echo-averaged magnitude images (1,3,5,7, slices).

Analysis: Qualitative inspection was performed on the 3D SWI data sets to evaluate performance over the entire brain volume. Quantitative analysis was performed on the central slice (using ImageJ) by identifying veins and plotting profiles through the veins and adjacent tissue. From these profiles, contrast was calculated as the signal difference between the vein and surrounding white matter[6] and was calculated for each σ and each mIP thickness; SWI contrast was then normalized by the contrast of the corresponding echo-averaged magnitude.

RESULTS and DISCUSSION: IEV-SWI images were successfully generated for all subjects. An example set of signal-intensity profiles is shown in Fig. 1a (single slice) for a range of σ values. Normalized contrast was calculated for the range of kernel sizes studied and in all cases peak contrast for IEV-SWI was observed when $0.006 \leq \sigma \leq 0.01$ (see Fig. 1b). A kernel size of 0.007 was selected as the value that provided consistently high vein contrast throughout the brain. Low σ values (< 0.004) reduced the contrast between veins and white matter, particularly in regions near the sinuses, as expected. Analysis at 3 and 7 T yielded similar results.

Representative images from 7T are shown in Fig. 2, which compares single slice and 3-slice mIP magnitude and IEV-SWI. Veins not apparent in the single-slice magnitude images (Fig. 2a) are clearly seen in the single-slice SWI (Fig. 2b); additional detail is shown in the magnified images. Without the SWI contrast provided by the IEV channel combination process, projection through at least 3 slices (3.75 mm) was required to see nearly as many peripheral veins (*i.e.* little contrast is present between vein and white matter); on the other hand, single-slice IEV-SWI enabled visualization of small vessels (diameters as small as 0.57 mm). In all cases where mIPs were generated, IEV-SWI provided better contrast than the corresponding magnitude mIPs (*e.g.* Fig. 2c and d).

CONCLUSION: Using optimized IEV channel combination, high susceptibility related contrast can be achieved even in single slice images, enabling visualization of small continuous veins in the brain.

REFERENCES: [1] Schweser et. al., MRM, 2013, 69: 1581–1593. [2] Liu, Drangova MRM, 2014, [3] Liu et. al., MRM, 2012, 68: 1303–1316. [4] Haacke et. al., MRM, 2004, 52: 612–618. [5] Denk, Rauscher, JMRI, 2010, 31: 185–191. [6] Deistung et al., MRM, 2008, 60:1155-1168.

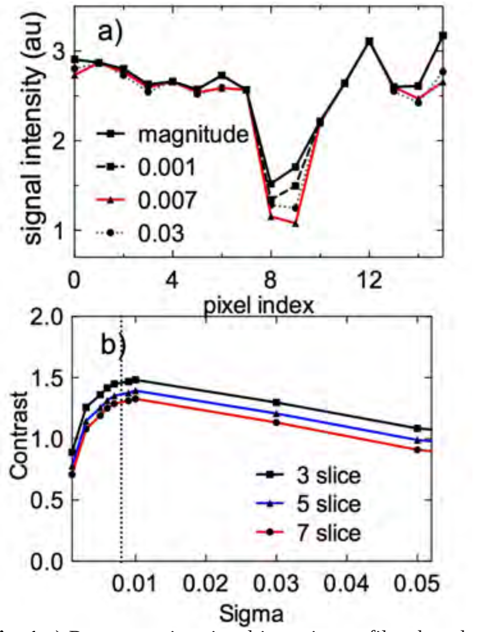

Fig. 1 a) Representative signal intensity profiles though a vein at varying σ. b) Normalized contrast plots as a function of increasing σ, demonstrating peak contrast near 0.007. Normalized contrast was not plotted for the single slice case, since contrast in the magnitude only images was very low, thereby exaggerating the apparent contrast in the SWI.

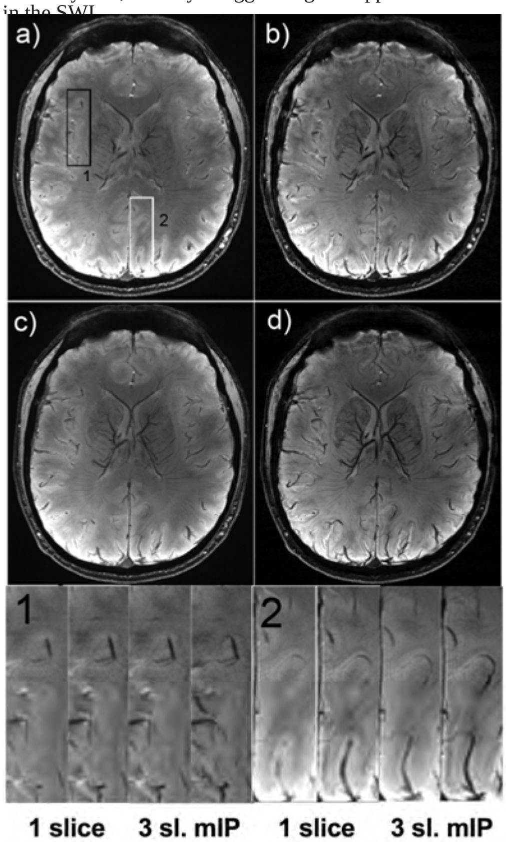

Fig. 2 Single slice (SS) magnitude image (a) and IEV-SWI (b). 3-slice mIPs through magnitude (c) and IEV-SWI (d). Magnified images demonstrate the increased vessel conspicuity using IEV-SWI.