High-Contrast and High-SNR SWI Venography with Multiple Echo datasets

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Introduction

Susceptibility Weighted Imaging (SWI) method is commonly used for Magnetic Resonance (MR) venography. The difference between SWI and conventional GRE imaging is that phase information of signal is incorporated to enhance contrast of image. The phase can provide excellent contrast between venous blood vessels and other tissues with susceptibilities that are different from the background tissue [1]. Although SWI is very powerful technique, SWI technique still has some weaknesses, regarding a trade-off between the gain of venous contrast and the loss of SNR. In this study, we propose a new approach to obtain high-contrast and high-SNR SWI venography with multiple echo datasets.

Methods

A brain of healthy volunteer was scanned with 3D multi-echo GRE pulse sequence at 3T(Siemens, Erlangen, Germany) for SWI with a matrix size of 256×256×50 (resolution of 0.8×0.8×1.6 mm^3), a FOV of 21.5cm×21.5cm. Repetition time was 124ms, flip angle was 15°, and forty echoes starting at 3.3ms and spaced by 3.01ms were collected. All image processing was performed using MATLAB (The MathWorks, Inc., Natick, MA) on a personal computer with 2GB of memory running Windows.

SWI first applies a strong low pass filter (Hamming filter). In standard SWI, filter in k-space with size 20 to 25% of the respective k-space dimension is used, since they lead to good phase contrast and suppression of phase wraps [2]. So, 128×128 size of Hamming filter is used in standard SWI experiment. The low-pass-filtered image is subtracted from the original image using complex division. This phase image is used to create phase mask. Standard SWI use the phase mask that is created by setting phase values above a threshold of 0° to unity, whereas all phase values below the threshold and larger than $-\pi$ are linearly scaled between zero and unity with zero corresponding to $-\pi$ [3]. Then, multiplying phase mask about 4 times into the original magnitude image results in improving visibility of venous vessels [1].

The proposed new SWI method applied various sizes of filter to each echo, first. Then, the best optimized filter sizes for different echoes were investigated. With the smaller filter size, the slowly varying phase variations were not always removed completely, whereas with larger filter size, small details in the phase images started to disappear. So, for a longer TE, relatively larger size of filter was demanded, because the spatial density of phase wraps increased. Thus, filter sizes ranging from 64×64 at TE=30.39ms to 120×120 at TE=60.49ms with increments for every additional 3.01ms was adapted in proposed new method. Second, a new phase mask which has different phase threshold value from standard SWI was designed for each echo. It was discovered that some range of phase about zero has little information for venogram by this experiment. So, finding optimal value of threshold with enhancing contrast of vein, with reducing noise was performed. There was a trade-off between the gain of contrast of vein and loss of SNR by means of threshold value. So, as the result of the experiment, −0.30 is the best value for all TEs. Third, depending on the echo time, the number of phase mask multiplications to optimize the contrast-to-noise ratio (CNR) in the SW images was varied. Phase masks acquired at different TEs were complementary in depicting the venous vasculature [4]. Phase mask acquired at a longer TE had a higher venous contrast and stronger noise, whereas phase mask acquired at a shorter TE had a higher signal-to-noise ratio. Thus, the former was multiplied more times than the latter. The number of multiplication varying from 11 at TE=30.39ms to 1 at TE=60.49ms with decrement for every additional 3.01ms resulted in better venous contrast.

All venograms were created by performing a minimum intensity projection (mIP) over targeted volumes. Standard and new improved SWI methods were implemented, and then, multi-echo susceptibility weighted images were averaged with different weightings. To evaluate the effect of these methods, CNR and standard deviations over several regions indicated by arrows in Fig 1, were calculated. The regions containing veins were selected manually with the matrix size of about 10×10.

Results

Fig 1-(a) shows that the averaged venography of original data from TE=30.39ms with every 3.01ms increment to TE=60.49ms. Although it has high SNR, the venous vasculature has low contrast. Fig 1-(b) is the averaged venography by the standard SWI at the same TEs with Fig 1-(a). The contrast of veins was increased, but SNR was degraded on the region of background tissue and some artifacts occurred. Fig 1-(c) shows the averaged venography by the proposed new SWI at the same TEs with Fig 1-(a). In Fig 1-(c), improvement of venous contrast was observed, without degrading SNR. Table 1 shows that CNR of the indicated regions in Fig 1. The CNR of venography using the new SWI were the highest in all cases, even in the case of failing to enhance CNR in region 3 by the standard SWI. This lower CNR in region 3 by the standard SWI than by the magnitude image was due to the increment of noise in background tissues (standard deviation of the background tissues increased). Also, the lower standard deviation of background tissues in the new SWI than that in the standard SWI means the high-SNR characteristic of the new SWI method.

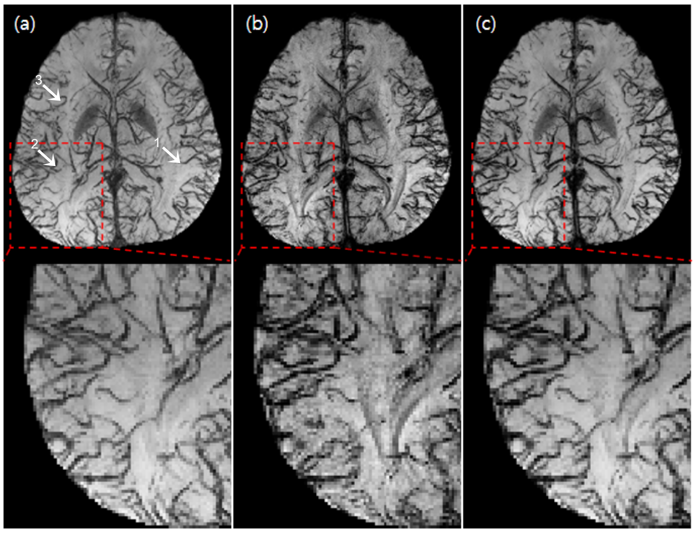

Fig 1. The averaged venography of (a) the magnitude image, (b) the standard SWI, and (c) the proposed new SWI from TE=30.39ms with every 3.01ms increment to TE=60.49ms.

Conclusion

This study demonstrates that the proposed new SWI method can effectively improve the venous contrast without degrading SNR. Weighted combination of the multi-echo SWI data gives an improvement to the venography compared to the conventional venography from single-echo SWI data.

Table 1. CNR over the regions indicated by arrows in Fig 1.

	region 1	region 2	region 3
(a) the magnitude Image	4.95* (4.21×10^{-9})**	6.36 (2.89×10^{-9})	7.12 (3.97×10^{-9})
(b) the standard SWI	4.98 (4.51×10^{-9})	7.62 (3.35×10^{-9})	6.31 (4.60×10^{-9})
(c) the new SWI	5.74 (4.40×10^{-9})	8.96 (3.29×10^{-9})	7.39 (4.57×10^{-9})

CNR* (Standard deviation of background tissues)**

References

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