Multi-echo susceptibility-weighted imaging with adaptive averaging

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Background

Susceptibility-weighted imaging (SWI) helps depicting hemorrhage and veins by incorporating phase information from long echo time (TE) signals to enhance contrast between paramagnetic substances and brain parenchyma [1]. An alternative of SWI uses multiple echoes averaged to improve signal-to-noise ratio (SNR) and is named susceptibility weighted angiography (SWAN) [2]. Since the averaging operation with signals from early echoes [3] inevitably results in a dilution of T2* weighting, it is anticipated that the SNR improvements and loss in contrast-to-noise ratio (CNR) present an obvious trade-off. In this research, an adaptive averaging scheme for multi-echo SWI is proposed, with weights of echoes adjusted according to the phase value of each voxel to achieve SNR improvements without sacrificing CNR.

Materials and Methods

Imaging data from three subjects were included. The 3D multiple gradient echo imaging (8 echoes) was conducted using a GE 1.5T MR system. The imaging parameters were as following: TR = 55msec, TE = 5.5 ~ 50.5msec, acquisition/ reconstruction matrix = 416×256/512×512, field of view = 240*240mm^2, slice thickness = 2mm, flip angle = 20°, slice number = 64 ~ 76, and bandwidth = 163Hz/pixel. The magnitude images of late 5 echoes were root mean squared to generate SWAN images. For SWI, the phase images were homodyne high-pass filtered to create the phase mask from the sixth echo (TE=38 ms) [1], followed by multiplying the phase mask four times with its corresponding magnitude image. For adaptive averaging, the magnitude images of the 5 late echoes were multiplied by the same phase mask four times as in SWI, and then averaged using the weighting function $W_{ij} = (-\theta_i/\pi)\times TE_j + (-0.5)\times(-\theta_i/\pi) + 0.5$, where W_{ij} is the weighting value at the ith voxel for the jth echo and θ is the phase value. Using this weight adjustment, voxels with more positive (diamagnetic brain parenchyma) and negative phase (hemorrhage or veins) was given more weighting on early and late echoes, respectively. Hence it improves SNR and maintains the susceptibility-related darkening effect.

Quantitative comparison of the three methods was made on minimum intensity projection (miP) of 7 slices because of its wide popularity in clinical diagnosis. For this purpose, the internal cerebral veins of both hemispheres and the neighboring white matter were selected as the target and reference region-of-interest (ROI), respectively. Standard deviations of signal intensity from bilateral homogeneous white matters of the parietal lobe were taken as the noise. The ratio between mean signal of reference ROI and the noise was taken as SNR, whereas the mean signal difference between target and reference ROIs divided by the noise was given as CNR. Conspicuity of the veins was further evaluated by plotting the signal profile (Fig.1) crossing the internal cerebral veins (line segments in Fig.2). The venous depth was defined as the signal difference between mean signal of pixels along line a and d and mean signal of pixels at valleys b and c (Fig.1). The venous width was defined by mean full width half maximum of pixels at valleys b and c (Fig.1). All three methods were evaluated for SNR, CNR, depth, and width for all subjects.

Results

The mIP images with adaptive averaging from one subject demonstrate higher vein-parenchyma CNR than SWAN and better SNR than SWI (Fig. 2a-c). The 1D signal profile of the bilateral cerebral veins from the image obtained using the proposed method is deeper and sharper than those with other two methods (Fig.2d). Quantitative analysis for the adaptive averaging method yields SNR/CNR/depth/width =**104±15/ 47.8±16.6/ 587.0±78.8/ 2.7±0.6 pixels** (Table 1), suitable for venous depiction.

Discussions

The adaptive averaging method benefits from the utilization of phase information as in SWI to provide the desired susceptibility contrast, at the same time improves the SNR of the surrounding brain parenchyma via signal averaging with the early echoes as in SWAN. Better visualization of the venous structure is thus obtained with the proposed approach. The weighting algorithm aiming at signal averaging only for the parenchyma can be further optimized depending on the target ROI.

References [1] Haacke et al., MRM, 2004;52:612-618; [2] Lummel et al., Neuroradiology, 2011;53:311-317;. [3] Denk et al., JMRI, 2010;31:185-191

subject	method	SNR	CNR	depth	width
A	SWI	70	44.5	550	4.1
	SWAN	195	89.5	502	2.7
	adapt	120	66	668	2.3
B	SWI	61	32	382.5	5.6
	SWAN	74	23.5	306	1.9
	adapt	102	33.5	510.5	2.3
C	SWI	51	33	574.5	3.6
	SWAN	143	66	390.5	2.4
	adapt	91	44	582.5	3.4
Mean±SD	SWI	**61±9.5**	**36.5±6.9**	**502.3±104.5**	**4.4±1.0**
	SWAN	**137±61**	**59.7±33.5**	**399.5±98.3**	**2.3±0.4**
	adapt	**104±15**	**47.8±16.6**	**587.0±78.8**	**2.7±0.6**

Table 1 Four image features with 3 methods for 3 subjects (A-C). *depth: venous depth; width: venous width; adapt: adaptive average method ; SD: Standard Deviation*

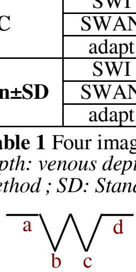

Figure 1 The 1-D schematic profile of cross section in the bilateral internal veins

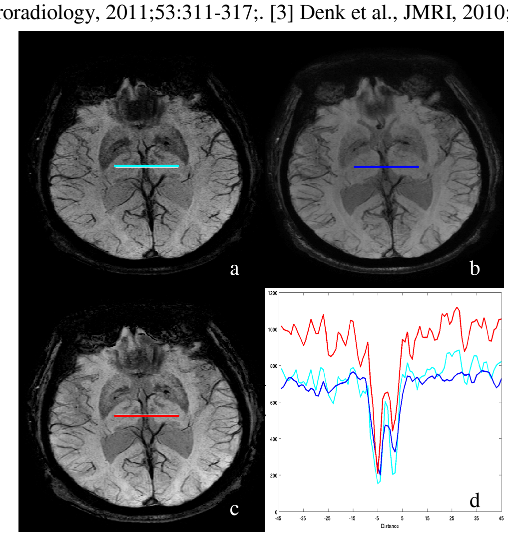

Fig.2 The miP images with (a) SWI, (b) SWAN, (c) adaptive averaging, and (d) the 1-D signal profiles of SWI (cyan), SWAN (blue), and adaptive averaging (red), showing improved conspicuity of the veins by adaptive averaging.