Optimized processing for various TEs for generation of angiography

Uehwan Kim[1] and Hyunwook Park[1]
[1]*Department of Electrical Engineering, Korea Advanced Institute of Science and Technology (KAIST), Daejeon, Korea*

Introduction

MR angiography (MRA) based on the time-of-flight contrast and MR venography (MRV) based on blood oxygenation level-dependent (BOLD) contrast are routinely used for imaging the cerebral vasculature in detail. The main drawback of both methods, however, is their long scan time typically ranging from a few minutes to 15 minutes. Recent studies [1] have attempted to reduce the scan time by producing MRA and MRV simultaneously using dual or multiple echo sequences. Although these studies successfully shortened the scan time and produced acceptable MRA results, intrinsic low signal to noise ratio (SNR) of MRV was not improved. Furthermore the BOLD contrast restricts projection over limited number of slices, which prevents depiction of overall vein vasculature. In this study, a new technique that mitigates the low SNR problem of MRV and portrays the overall vein vasculature is suggested and demonstrated.

Materials and Methods

Pulse sequence and data acquisition

Fig. 1 shows the sequence diagram of the proposed method. A second echo and a third echo are added to a conventional 3D spoiled gradient-echo sequence used for the multiple overlapping thin slab acquisition (MOTSA) technique. Data from the first echo are used for MRA and data from the second and the third echoes are used for MRV. Flow compensation in readout direction and slice selection direction is applied for the first echo. The fly-back gradients placed in the middle of two echoes in readout direction maintain the polarity of second and third echoes.

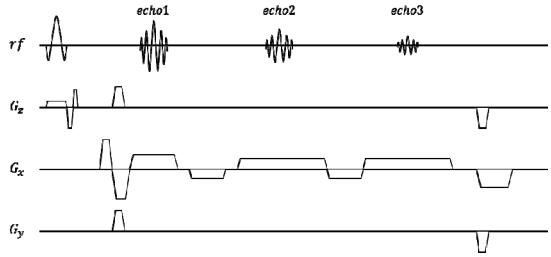

Figure 1. The sequence diagram for the proposed method.

To verify the performance of the proposed method, the MRA and MRV data were acquired from one healthy volunteer using a 3 Tesla (T) MRI system (Siemens Magnetom Verio, Erlangen, Germany). A relatively low readout bandwidth (BW) was selected for the second and the third echoes to improve SNR of MRV data (BW1/BW2/BW3 = 391Hz·px^{-1}/156Hz·px^{-1}/156Hz·px^{-1}). Other imaging parameters are as follows: repetition time (TR) = 28ms, the first echo time (TE1) = 5.9ms, TE2/TE3 = 15ms/24ms, flip angle = 20°, field of view (FOV) of a single slab = 200x200x22mm^3, matrix size of each slab = 320x320x22 with an in-plane resolution = 0.6x0.6mm^2, number of overlapped slices = 6, number of slices per slab = 22, and number of slabs = 7.

Image reconstruction

All data processing algorithms were implemented using MATLAB (The Mathworks, Inc., Matrick, MA). Before applying MOTSA technique to data from the first echo to generate MRA, venous signals were suppressed using susceptibility weighted imaging (SWI) technique. For SWI, magnitude of complex filtering (MCF) method [2] was employed to reduce susceptibility induced artifacts. The processed multi-slice images are then projected.

For MRV, data from the second and the third echoes were used. Data from the second and the third echoes can be either processed separately to visualize evolution of vessel signal or averaged to increase SNR. In both methods, SWI technique is applied. As TE gets longer, phases from both tissue characteristic and inhomogeneity develop. Accordingly, different size of low pass filter (LPF) for removal of phase from inhomogeneity and number of multiplications of phase to emphasize contrast to noise ratio (CNR) should be adopted for each TE. Optimal LPF size as function of TE has been reported in [3]. The optimal number of multiplication can be achieved by computer simulation using theory shown in [4].

Finally, simple subtraction method was developed to visualize the overall vasculature of veins. Susceptibility weighted images were subtracted from the original magnitude images from the first echo. Since susceptibility weighting decreases signals from veins, the subtraction highlights veins. This process is described in Fig. 2. MOTSA technique was applied to the entire volume after the subtraction processing.

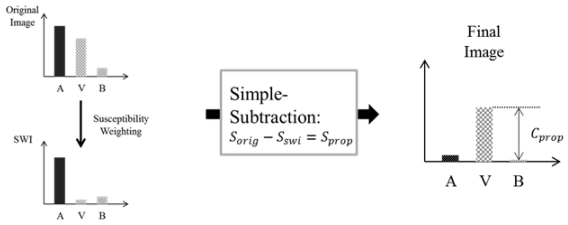

Figure 2. Subtraction for enhanced venogram.

Results

From computer simulation of SWI, the optimal numbers of multiplications for TE=15ms and TE=24ms were 3~4 and 2~3, respectively. LPF width was modified by the filter width equation in [3]. In Fig. 3, the left image shows venous signal suppressed MRA and the right image shows the original image. Arrows in Fig. 3 (b) indicate suppressed signals. Fig. 4 (a) displays MRV from the second echo and (b) does MRV from the third echo. Fig. 4 (c) shows averaged MRV. As TE gets longer, some veins are mingled up and appear as a single vein. Such veins are indicated by arrows in Fig. 4 (a). By taking average, SNR improves while maintaining vessel contrast as in Fig. 4 (c). Fig. 5 shows overall vein vasculature from the proposed method which extracts vasculature from phase information.

Discussion and Conclusion

In the proposed method, large veins are not effectively suppressed though small veins are suppressed enough. Moreover, the proposed method depicts large vessels rather than small vessels with bright signal after subtraction. For improvement of the image qualities of the proposed method, finer processing of phase information is crucial. Other SWI filtering methods or phase extraction methods from multiple echoes would improve the overall performance. Furthermore, combination of magnitude from the first echo and phase from the last echo would improve the vasculature image. However, low SNR in longer TEs contaminates vessel visibility.

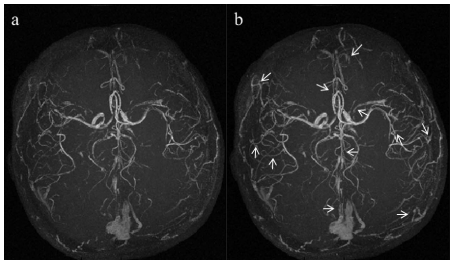

Figure 3. In-vivo MRA results. Venous signal suppressed MRA (a), Original image (b).

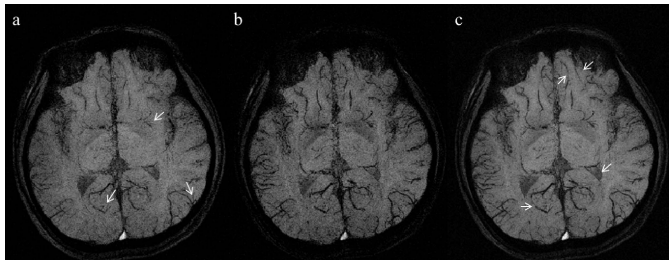

Figure 4. In-vivo MRV results. MRV from echo 2 (a), MRV from echo 3 (b), MRV averaging signals from echo 2 and 3 (c).

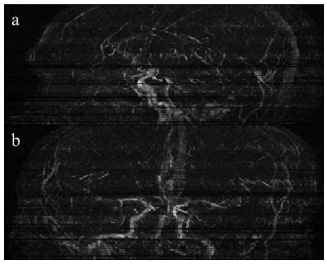

Figure 5. Vein vasculature extracted from phase. Sagittal (a), coronal (b).

In conclusion, a new method acquiring MRA and MRV simultaneously that improves SNR of MRV and portraits overall vein vasculature is developed.

References

[1] Du YP, Jin Z. Simultaneous acquisition of MR angiography and venography (MRAV). Magn Reson Med. 2008;59(5):954-8. [2] Lee Y, Han Y, Park H. A new susceptibility-weighted image reconstruction method for the reduction of background phase artifacts. Magn Reson Med. 2013 May 14. [3] Denk C, Rauscher A. Susceptibility weighted imaging with multiple echoes. J Magn Reson Imaging. 2010;31(1):185-91 [4] Haacke EM, Xu Y, Cheng YC, Reichenback JR. Susceptibility weighted imaging (SWI). Magn Reson Med. 2004;52(3):612-8.