# High-quality Multi-contrast Susceptibility-Weighted Venography using Tissue-dependent Denoising Method

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## Introduction

Susceptibility weighted (SW) venography from magnetic resonance (MR) images is an useful image for diagnosis of venous diseases because it can produce anatomical structure of veins without injecting any contrast agents unlike other imaging techniques such as x-ray or computed tomography. This SW venography can be produced from gradient-recalled echo (GRE) sequence data, but this single-echo venography can provide only a limited information of vein structures. To produce more informative SW venographies that covering whole vein structures, multi-contrast venographies can be obtained by using multi-gradient recalled echo (MGRE) sequence. However, in this case, the signal-to-noise ratio (SNR) of venography at each echo is degraded due to the short scan time for each echo image. In this study, an effective denoising method was developed to generate high-SNR, high-resolution, and multi-contrast SW venographies from MGRE MR acquisition. Because the SW venography is produced by multiplying the magnitude image by the phase mask which is obtained from the phase data, denoising process was performed to both magnitude and phase data simultaneously. The denoising process was performed by neighboring spatially independent voxels depending on their tissue-relaxation properties in the successive multi-echo images.

## Methods

For *in vivo* experiments, a 3D brain was scanned with a MGRE pulse sequence using a 3T MRI system (Erlangen, Germany). The field of view was $215 \times 215 \times 51.2\text{mm}^3$, slice thickness was 1.6mm. Other sequence parameters were TE1=5.67ms, ES= 5.51ms, flip angle=30°, bandwidth=444Hz/Px, resolution =512×512, interpolated to 1024×1024, and the number of echoes was 16. All image reconstruction and processing were performed using MATLAB (The MathWorks, Inc., Natick, MA).

Our proposed denoising method averages voxels that only belong to the same tissue using tissue-relaxation properties of each voxel. In temporal domain, decaying complex signals of each voxel is obtained. And then the denoising process was done by following 3 steps: (1) Distances between two decaying complex signals were calculated by: $\mathrm{D}(\mathrm{r},\mathrm{s}) = \left\| \overrightarrow{S(r)} - \overrightarrow{S(s)} \right\|_2$, where $\overrightarrow{\mathrm{S(r)}}$ and $\overrightarrow{\mathrm{S(s)}}$ are the decaying complex signal of voxel r and s, and $\mathrm{D}(\mathrm{r},\mathrm{s})$ is the distance between $\mathrm{S(r)}$ and $\mathrm{S(s)}$; (2) $B_p(r)$ which is the set of neighboring voxels for a specific voxel r to be denoised was chosen by thresholding distances between voxel r and other whole voxels in the image; (3) Finally, the denoising was done for voxel r by : $S_{NL}(\mathrm{r}, t_i) = \sum_{s \in B_p(r)} S(\mathrm{s}, t_i)$ where $S_{NL}(\mathrm{r}, t_i)$ is the filtered value of the voxel r at the *i*-th echo image. Phase mask was generated at TE=38.73ms by 128×128 hamming filter and threshold was 0.2π. SW venographies for all TEs were obtained by multiplying the minimum intensity projection (mIP) of phase masks by the mIP of magnitude images,

## Results

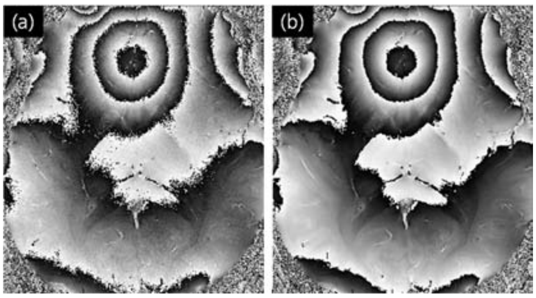

**Fig 1.** Phase images of a specific slice at TE=38.73ms (a) original phase image, (b) denoised phase image by the proposed denoising method

Fig 1 shows the original phase image and the denoised phase image of a specific slice at TE=38.73ms. Fig 1-(a) shows low contrast of structural information such as veins and boundary of white and gray matter due to low SNR. Denoised phase image in fig 1-(b) shows relatively high contrast and high SNR image compared to (a). In this figure, the noise was effectively reduced and the contrast of image was highly improved especially in the posterior by the proposed method.

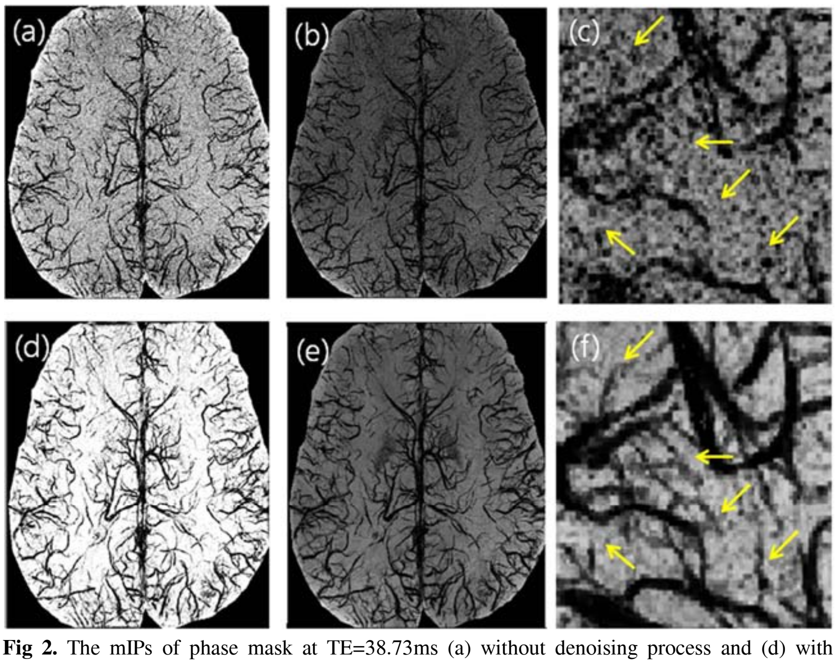

**Fig 2.** The mIPs of phase mask at TE=38.73ms (a) without denoising process and (d) with denoising processs. The SW venography at TE=38.73ms (b) without denoising process and (e) with denoising process. (c, f) are enlarged SW venographies of (b,e).

Fig 2 shows mIPs of phase mask and SW venographies at TE=38.73ms without denoising process (a,b) and with denoising process (d,e). The denoised phase mask (d) is much highly improved than the original mask (a). So this results show that the accuracy of measured susceptibility of each tissue is greatly improved. And the denoised SW venography (e) is also highly improved than the original SW venography (b). While thin and detail veins indicated by arrows were not identifiable in the original SW venography (c), those veins became clearly identified in the denoised SW venography (f).

## Conclusion

This study demonstrates that the proposed denoising method can reduce noise effectively on both the phase and magnitude data. The magnitude and phase data were simultaneously denoised by neighboring complex decaying signals using the tissue relaxation property. Consequently, the resulting SW venographies showed substantial improvement.

**Reference** [1] U. Jang, et al., NeruoImage 70, 2013. [2] D. Hwang, et al., NeuroImge 74, 2013. [3] G. Gerig, et al., IEEE Trans. Med. Imaging 11, 1992.

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