Presurgical Visualization of Cerebral Surface Veins with Susceptibility Weighted Imaging

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Introduction: The cerebral vascular architecture and in particular the geometrical relationship between pathologies and blood vessels are of tremendous diagnostic and therapeutic interest [1]. In particular, veins on the brain's surface can be used as landmarks since the spatial relationship between sulci and blood vessels is not altered by brain edema-shrinkage, or brain shift during surgery [2]. Magnetic resonance venography (MRV) based on a susceptibility weighted imaging (SWI) [3,4] allows us to visualize the intracranial venous vasculature at high spatial resolution without the use of a contrast agent. One drawback of SWI has been the poor visualization of veins at the brain's surface. We present an alternative data processing scheme and demonstrate visualization of surface veins based on SWI data.

Theory and Methods: Susceptibility Weighted Imaging (SWI) [3,4], formerly called BOLD MR Venography, is a technique that combines magnitude and phase of a high resolution fully flow compensated 3D gradient echo scan [5]. The contrast mechanism is based on the blood oxygenation level dependency (BOLD) of the signal, which causes veins to appear dark in the images. While this technique produces excellent contrast between veins and surrounding tissue, visualization of veins at the brain's surface has been poor. The reason for this is that the phase images need to be high pass filtered to remove the influences of background field inhomogeneities. High pass filtering is performed by subtracting the low pass filtered data from the original data. The steep transition between the brain and the noise outside the brain also gets smoothed due to the low pass filter, which heavily degrades the visibility of veins on the brain's surface. Therefore, an alternative low-pass filter, bilateral filtering, was implemented to preserve the edges while smoothing the image.

MRI Acquisition; Fully flow compensated 3D gradient echo data [5] of volunteers were acquired on a 3T system (Achieva Philips Medical Systems) using fully compensated 3D gradient echo data [5] of a spherical phantom and volunteers were acquired on a 3T system (Achieva Philips Medical Systems) using an eight-channel SENSE head coil (TE/TR/α=20/29/17^o, matrix = 440x296x40, FOV=220x166x80, reconstruction matrix = 528x528x80, acquisition time = 4.5min). Brain anatomy was acquired using a 3D T1 weighted FFE scan with the same field-of-view (TE/TR/α = 3.5/7.4/8^o, matrix =220x168x80). The protocol was approved by the local ethics committee and all subjects gave informed written consent. Both magnitude and phase images were reconstructed. The phase images were unwrapped using the freely available unwrapping tool ΦUN [6].

Bilateral filter: The bilateral filter [7] was applied to the unwrapped images in 2D on a slice by slice basis. The phase images were converted into a phase mask and multiplied with the corresponding magnitude images to create susceptibility weighted images. These were median filtered [8] to suppress the background tissue.

Vesselness filter and Vessel Enhancing Diffusion: The vesselness filter is based on the second order image information represented by a Hessian matrix. The eigensystem is analyzed to construct a function that can distinguish tubular structures from non-tubular structures [9], enabling the filter to select vessels, which are dark in comparison to its surroundings. Vessel enhancing diffusion enhances vascular structures. VED, an iterative process is processed so that the vesselness filter output is improved in the next iteration. This method depends on the vessel-likeliness which is found in the vesselness filter [10].

Results: Bilateral phase filtering improves the visibility of surface veins without degrading the visibility of other veins. Fig 1. Displays the 3D rendering of the surface veins overlaid onto a structural scan. Note the close spatial relationship between sulci and veins.

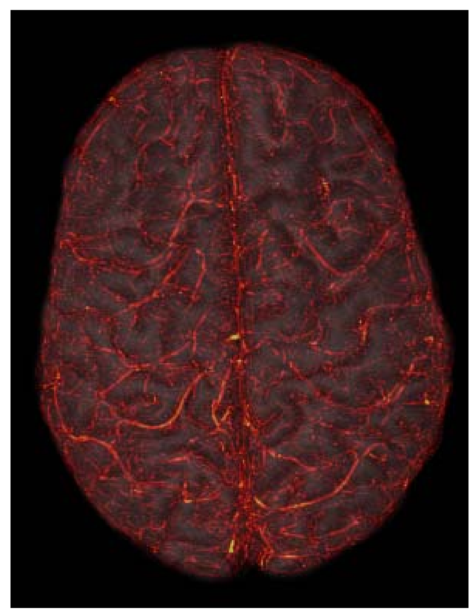

Fig 1. 3D reconstruction of the segmented veins overlaid onto the structural scan.

Discussion: The quality of SWI-venograms depends not only on the data acquisition protocol but also on subsequent image reconstruction and post-processing steps. To achieve high quality, high-resolution venograms, all of these components should be optimized accordingly. Koopmans et al [11] showed that at 7T, good venograms can be acquired without using the phase information. If phase filtering is to be used in post-processing, the data acquisition protocol should be adjusted to optimize the phase contrast between veins and background tissues, and image reconstruction should be implemented such that this phase information is preserved and enhanced. Compared with Gaussian filtering, bilateral filtering improves the specificity at sharp boundaries and therefore, it is a better method for both smoothing and edge preserving than traditional methods. The segmented veins are visualized without the need of contrast agents and the 3D MRI reconstruction of the segmented veins overlaid onto the structural brain provides landmarks for clinical purposes such as image-guided navigation of the brain surface. Future work will aim at: (1) further optimization of data acquisition, mainly in terms of echo time and spatial resolution; (2) computational efficiency of data processing; and (3) validation of the technique by comparison with digital photography of the brain during surgery.

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