Segmentation of Venous Vessels using Multi-Scale Vessel Enhancement Filtering in Susceptibility Weighted Imaging

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Introduction

Susceptibility weighted imaging [1] is a technique which allows to visualize the cerebral venous architecture with high spatial detail. Visualizing the vascular anatomy in a three dimensional computer model may improve diagnosis of vascular diseases and allows to study the structural and functional characteristics. For this purpose a vascular extraction algorithm is needed. This work introduces a technique for the segmentation of venous vessels in SWI data.

Material and Methods

High-resolution 3D scans were acquired with a velocity compensated gradient-echo sequence at 1.5T (TR/TE/FA=67ms/40-50ms/25°). Phase information was unwrapped [2] and negative phase values were scaled linearly from 0 to 1, whereas positive values were set to unity. This phase mask was multiplied four times with the magnitude information to obtain susceptibility weighted images. A multi-scale vessel enhancement filter algorithm [3] was applied to a 2D minimum intensity projections (mIP) over 10 slices (12mm) of SWI images (venogram) and to a 3D SWI dataset. For vessel enhancement of the 3D data set the Hessian matrix and its eigenvalues λ_i were determined. Scales were computed by Gaussian filtering with standard deviations σ from 0.5 to 2.1 in 0.2 steps with a normalization factor γ of 1.5. For each scale the vessel function *vf* was computed using the Frobenius norm of the Hessian matrix *SF*, with α = β = 0.5 and c was the highest value of the Hessian matrix divided by 3. These vessel functions were combined using a maximum intensity projection over all scales.

$$vf(x,y,z) = \begin{cases} 0 & for\ \lambda_2(x,y,z) > 0 \\ 0 & for\ \lambda_3(x,y,z) > 0 \\ \left(1 - \exp\left[-\frac{\left(\frac{|\lambda_2(x,y,z)|}{|\lambda_3(x,y,z)|}\right)^2}{2\cdot\alpha^2}\right]\right) \cdot \exp\left[-\frac{\left(\frac{|\lambda_1(x,y,z)|}{\sqrt{|\lambda_2(x,y,z)\cdot\lambda_3(x,y,z)|}}\right)^2}{2\cdot\beta^2}\right] \cdot \left(1 - \exp\left[-\frac{SF(x,y,z)^2}{2\cdot c^2}\right]\right) \end{cases}$$

The resulting data were thresholded and skeletonizationed. The performance of the 2D and 3D vessel enhancement algorithm was compared using maximum intensity projection (MIP) over 41 slices.

Results

Figure 1 shows the result of vessel enhancement filtering. In the 2D venogram (Fig. 1(a)) veins are visible as dark tubular structures. Due to multi-scale vessel enhancing line-like structures are highlighted, whereas tissue is suppressed (Fig. 1(b)). Besides the boundary of the brain the separation of the two hemispheres is also enhanced. By masking of the parenchyma it was possible to remove the boundary of the brain. In the binary skeletonized image (Fig. 1(c)) the visualization of vessel connections has been clearly improved. Figure 2 shows a maximum intensity projection (MIP) of the multi-scale enhanced images. The application of the three dimensional multi scale enhancement algorithm (Fig. 2(b)) was able to suppress noise clearly and the delineation of vessels was improved in comparison to the 2D enhancement algorithm (Fig. 2(a)).

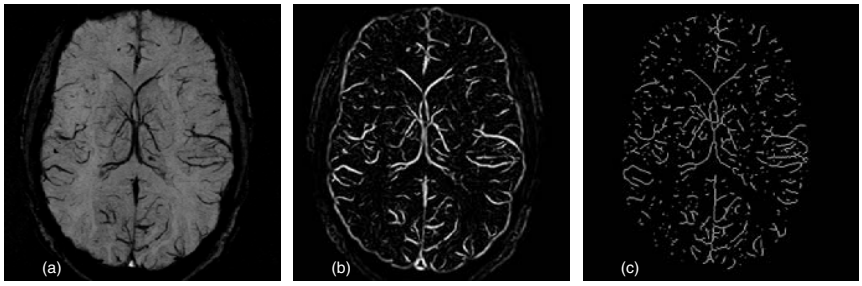

Fig. 1: *Segmentation of vessels from SWI venograms. (a) The venogram test image (mIP over 12mm). (b) The test image after multi-scale vessel enhancement filtering. (c) Enhanced image after thresholding and a skeletonization algorithm.*

Discussion

Vessel enhancement filtering on SWI data is able to highlight venous vessels. This allows to follow vessels after thresholding by using a semi-automatic seed-growing algorithm. Since the angle between the vessels and the magnetic field as well as the vessel enhancement filtering operation have an influence on the appearence of vessel size, centre-line extraction with subsequent deformable models may be able to further improve visualization. Such binary vessel masks may help to determine areas where the assumption of a vascular network is not valid. This can be used in fMRI or the determination of cerebral oxygen extraction fraction maps [4].

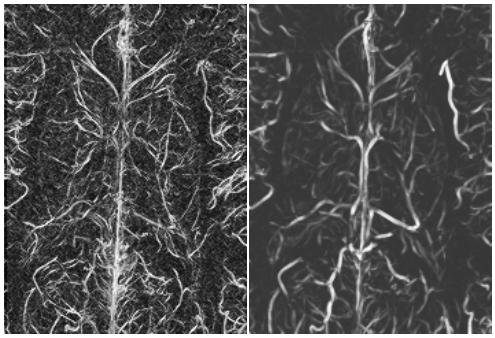

Fig. 2: *Vessel enhancement filtering applied on SWI data (a) slice by slice in 2D and (b) 3D with scales varying from σ = 0.5 to 2.1 in 0.2 steps. The results are visualized over a MIP of the enhanced data of 41 mm.*

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References

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