Semi-automated visualization and segmentation of cerebral veins from QSM

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Target audience. Physicians and scientists interested in automated vessel segmentation and characterization from MRI.

Purpose. Susceptibility MRI provides contrast of the brain's venous vasculature due to the presence of paramagnetic deoxyhemoglobin molecules in cerebral veins. Although susceptibility-weighted imaging has gained popularity to image veins in clinical applications such as stroke [1] and traumatic brain injury [2], this method suffers from non-local and orientation-dependent effects that may prevent accurate identification of brain vessels. The purpose of our study is to demonstrate visualization and segmentation of cerebral veins from quantitative susceptibility maps (QSMs), a new MRI contrast reconstructed from phase images.

Methods. *MRI acquisition.* Ten young, healthy volunteers were scanned with a 32-channel coil on a Siemens 3T Trio system. 3-dimensional gradient echo images for susceptibility mapping were acquired with full flow-compensation along each axis at all echoes. Axial magnitude and phase images were collected with TR = 23ms; TE = 7.2/17.7ms; resolution = 0.875x0.875x1mm^3, matrix = 226x256x144; and BW = 260Hz/pixel. *QSM reconstruction*. Phase images were combined offline and processed with Laplacian unwrapping [3]. Background field was removed with SHARP filtering [4] and QSM reconstruction was performed with a fast Split-Bregman algorithm via total variation regularization [5]. *Segmentation.* We utilized a new method for extracting a whole vessel tree using a high order tensor vessel tractography approach inspired by Higher Angular Diffusion Imaging techniques [6, 7]. One advantage of the method is the seamless modeling of the n-furcations (i.e. bifurcations of coronary arteries, quadfurcations of circle of Willis) jointly with tubular sections within the same mathematical model. The model is achieved by embedding a general Cartesian tensor into a 4-dimensional space so that antipodal asymmetries in Y-junction-like situations, which are abundant in vascular trees, could be modeled. Starting from a few seed points (e.g. 5-6) , an entire cerebral vein tree can be captured from the QSM by this technique, which provides the vessel orientation, its centerline (central lumen line), its thickness (vessel lumen diameter), locations of branching points, and lengths of branches. Furthermore, it takes up to 10 minutes to extract whole vessel tree including user interactions. An intermediate result of the method is depicted in Figure 1.

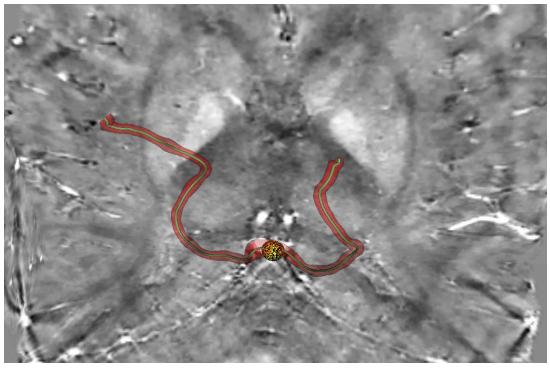

Figure 1. Intermediate step of the vessel tractography algorithm: Centerline of the vessel (green), extracted surface surrounds centerline (red), which provides the radius information of the vessel at each centerline point, and detected junction point (yellow) are shown.

Results. Reconstruction of QSM maps, extracted vessel centerlines, and vessel surface renderings for two sample subjects are shown in Figure 2. Mean estimated vessel radius was 4.05 ± 0.13 mm in the sagittal sinus, in 3.37 ± 0.49 mm in the straight sinus, and 1.21 ± 0.78 mm for smaller pial vessels Our estimated vessel radii within the expected physiological range from previous ex-vivo studies, which estimate a mean radius of 4.9mm in the posterior portion of the sagittal sinus and radius of ~1mm for para-sagittal pial veins [8]. For each vessel branch, mean estimated centerline length was 181 ± 22 mm in the sagittal sinus, 53 ± 5.41 mm in the straight sinus and 1144 ± 113 mm for smaller pial vessels. Mean estimated number of vessel branches for ten datasets is 124.4 ± 15.07. After cerebral vessels are extracted from QSM images, they are labeled into sagittal sinus, straight sinus and pial vessels by selecting a radius threshold of 2.5 mm, which are shown in Figure 2.

Conclusion. QSM images reconstructed from MRI phase provide accurate depiction of vein morphometry in the brain. Combined with automated segmentation of vessels, this method is a powerful new tool to create vascular models that could enable population studies of vein structure and physiology in health and diseases.

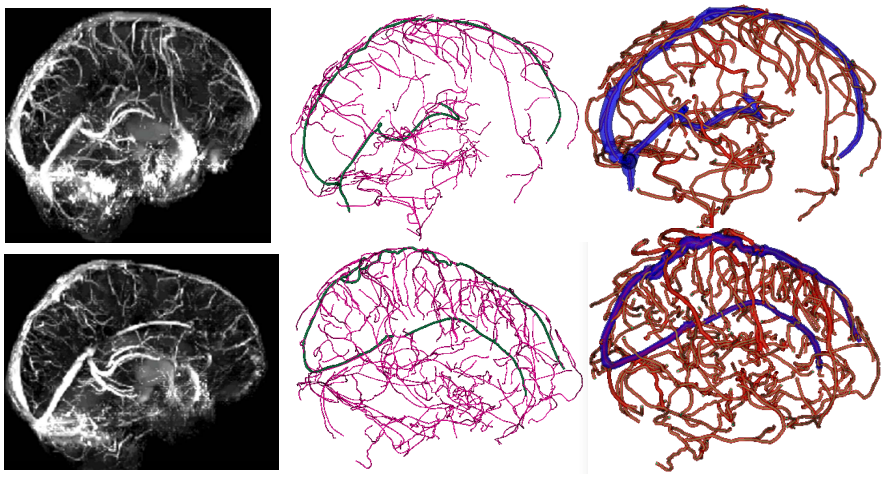

Figure 2. Maximal intensity projection view of reconstructed QSM maps, extracted centerlines of sagittal-straight sinus (green), and smaller vessels (pink), and vessel surface renderings for sagittal-straight sinus (blue) and smaller pial vessels (red) are shown in two healthy subjects.

Mean ± std (mm)	Radius	Length of the vessel
Sagittal Sinus	4.05 ± 0.23	181 ± 22
Straight Sinus	3.47 ± 0.39	53 ± 5.41
Pial vessels	1.21 ± 0.45	1144 ± 113

Table 1. Metrics of vessel morphometry (radius, length of vessel branch) are observed in average of ten subjects from automated segmentation for sagittal sinus, straight sinus and pial vessels separately.

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