Towards Characterization of the Cerebral Venous Vessel Network using QSM: Extraction of Vessel Radii and Lengths

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TARGET AUDIENCE – Scientists with interest in three-dimensional data representation, and characterization of the cerebral venous vessel network.

INTRODUCTION – The ability to characterize the brain's venous network with quantitative data is of high importance for radiologists to better diagnose, treat and plan surgical interventions. Venous blood vessels can be depicted in high-spatial detail and accuracy using quantitative susceptibility mapping[1]. With this technique enabling access to the whole brain venous network, the network topology can now be characterized. This work is the first step toward providing novel computer-aided diagnosis tools which allow automatic analysis of the venous network and detection of abnormalities. **In this contribution, we start from our previous work of segmenting susceptibility maps to present an approach for quantifying the cerebral venous vessel network from QSM images. We demonstrate the local variation of radii and segment lengths across selected parts of the venous network**.

METHODS – *Data Acquisition:* Data were measured with a fully flow compensated 3D single-echo gradient-echo sequence (TE/TR/FA/BW = 10.5ms/17ms/8°/140Hz/px, voxel size = (0.4×0.4×0.4) (mm^3) on a 7 T MRI system (MAGNETOM, Siemens, Erlangen, Germany). The scans were carried out in three different orientations of the head with respect to the magnetic field to compute susceptibility maps using the COSMOS approach.[1] *Data Processing:* The complex GRE data sets acquired in tilted head positions were registered to the data set acquired in normal head position using FLIRT [2] and the automated registration toolbox (ART, http://www.nitrc.org/projects/art). Phase aliasing was resolved by 3D phase unwrapping, and background phase contributions were eliminated with the SHARP technique.[3] Based on all three background corrected phased data sets susceptibility maps were computed using the COSMOS technique.[1,3] The susceptibility maps were normalized with respect to cerebrospinal fluid (CSF). Our previously presented pipeline was applied to segment the venous network, and the three dimensional surface representation of the vessels was used as basis for this topology study. To this end, the main connected components were firstly extracted from the surface mesh. Each connected component was considered to be a tree (i.e. no closed loop, no back branching). Secondly, we computed the centerlines of each extracted connected components from the whole network using a method proposed by Antigua et al.[4] relying on computational geometry and graph theory algorithms (Voronoi diagram, shortest path). Using Antigua's method ensures that the computed centerline segments always remain inside the three dimensional surface describing the vessel branches. Thirdly, radius information is obtained by estimating the maximal inscribed sphere for each segment point on the vessel's centerline. The computed trees were processed to extract the vessels radii and lengths statistics for each branch. Finally, radii information were projected on the vessel tree to better visualize its spatial repartition across the vessel network.

RESULTS – Based on the reconstructed vessel network, only the three largest connected vessel trees were used for analysis. Figure 1 shows these trees labeled as Part I, II and III. Part I, the largest component, consists of veins of the deep venous network, the straight sinus (SS), the inferior sagittal sinus (iss) and part of the superior sagittal sinus (SSS). Part II and III are smaller vessel trees connected to the SSS. For each component, a network was obtained like the one presented in the enlarged part of Fig. 1. The tree structure is clearly visible and we observed that the higher the branching level (i.e., the number of branches along the vessel pathway starting from the sinus veins), the smaller the vessel radii. Even thin vessels (radius of 0.2mm) of the venous network as shown in Fig.1 (large white arrows) could be extracted. Fig. 2 shows the repartition of the measured vessels radii of the Part I network. As we can see from the visualization in Fig. 1, the histogram of the radii distribution (Fig. 2) shows that Part I is composed of a large proportion of small vessels (radius <0.7mm) and few (<1%) big vessels (radius >2mm, such as SS and SSS). The analysis of the vessel segment lengths of Part I (Fig 3) reveals a high density of short vessels (<5mm). Part II and III are both topologically similar and their network analysis shows similar length statistics with means of (3.4±2.8) mm and (3.42±2.6) mm respectively.

DISCUSSION – We have presented a non-invasive approach for extracting and studying quantitative parameters of the venous network such as vessel radii and segment lengths using venous segmentation results based on quantitative susceptibility maps. There has been extensive work on vessel size imaging[5] (VSI). However, these studies are all focused on determining capillary parameters through indirect measurements,[6,7] where the underlying theory breaks down for vessel radii above 100µm. Our approach focusses on the characterization of the macrovasculature and can therefore be used as a complementary method to VSI. Since the network reconstruction is based on QSM data, correlations between physiological and topological parameters such as the relationship between blood oxygenation and vessel radii can be investigated. In future, the proposed network analysis will be extended to extract further topology describing parameters such as branching rate, torsion and tortuosity measures which are needed by radiologists for tumor characterization[8]. Moreover, our centerline network could also be applied as a feature for image registration and to determine differences across different subjects.

CONCLUSION – Sophisticated analysis of venous vessel segmentation based on centerlines enables to determine vessel radii and segment lengths locally providing a better description of the venous network. In future, automatic quantitative characterization of the venous network may improve the decision making process of radiologists to diagnose and to stage diseases associated with venous malformations.

REFERENCES: 1. Haacke E.M. et al. 2010 Magn Reson Imaging 32(3):663–76; 2. Jenkinson M. et al. NeuroImage 2002, 17(2):825–84. 3 Schweser F. et al. NeuroImage. 2011;54(4):2789–807. 4. Antiga L. et al. IEEE Transactions on Medical Imaging 2004, 23(6). 5. Troprès I. et al. Magn. Reson. Med 2001, 45:397–408 6. Jochimsen T.H. et al. Neuroimage 2010, 51,765–774. 7. Shen Y.. et al. Magn. Reson. Med. 2013;69:1541–1552. 8. Bullitt E. et al. Acad. Rad. 2005 ; 12(10) :1232–1240

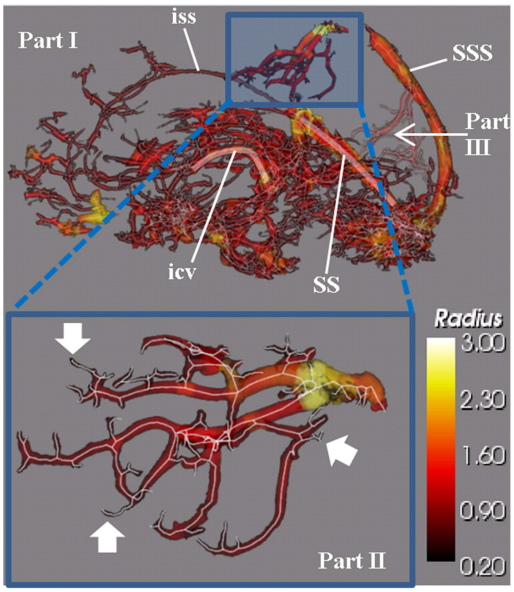

Fig. 1: Three-dimensional reconstruction of the whole vessel network created from the segmentation of QSM. The radius information is mapped onto the surface. The three largest connected vessel trees are displayed only. Extracted centerlines of part II are displayed in a closer view.

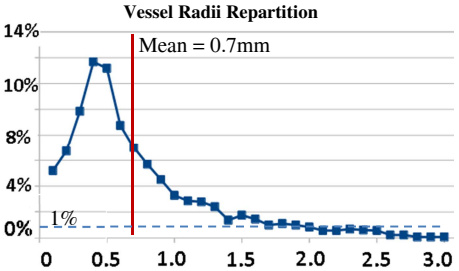

Fig. 2: Histogram plot of the repartition of the measured vessel radii of Part I. The x-axis represents the radii in mm and the y-axis the vessel segment count (% of the vessels)

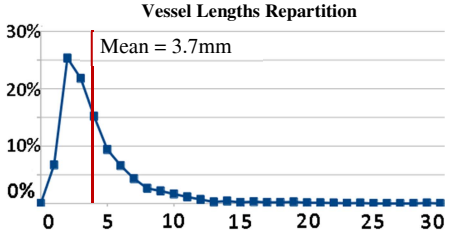

Fig. 3: Histogram plot of the repartition of the vessel lengths of Part I. The x-axis represents the lengths in mm