VesselMapper - A Robust Vessel Segmentation Algorithm for 3D Images

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Introduction:

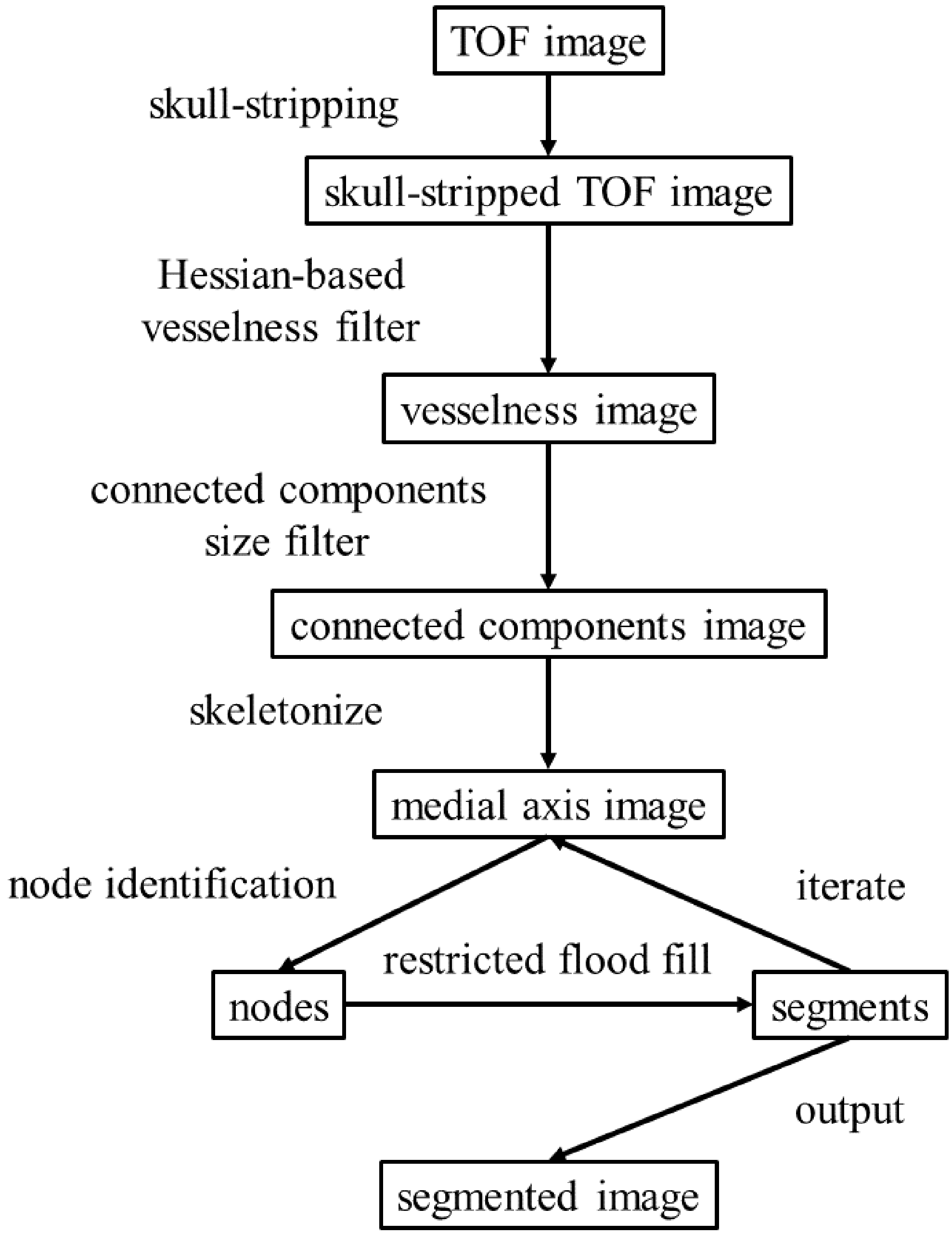
Blood vessel assessment is an important procedure in diagnostics based on medical imaging, and an automated algorithm for vessel segmentation could provide crucial information for detecting anomalies and other downstream tasks. In this study, we propose VesselMapper, a robust vessel segmentation algorithm for 3D images. We applied the algorithm to human brain time-of-flight (TOF) magnetic resonance angiography (MRA) images, and characterized morphological features of the extracted blood vessels in the brain.

Methods:

Whole-Brain TOF MRA images were collected on a 7T Siemens scanner at the University of Pittsburgh (slice number = 354, voxel size = 0.38 x 0.38 x 0.38 mm, 12 mins). The fully automated vessel segmentation method, VesselMapper, was implemented in Python 3 and ITK 5.3 (www.itk.org). The major steps of the proposed algorithm are outlined in the flowchart (Fig. 1). Specifically, the vesselness of a given voxel, representing the probability of the voxel belonging to a vessel, is calculated using the Hessian matrix. Connected components of the vesselness images are extracted and thresholded to remove small components due to noise. To further correct for noise-related gaps or local blobs/clusters in the vessels, we develop an iterative approach to estimate the medial axis for each vessel, and generate a skeletonized vessel map.

In this iterative approach, we first identify critical nodes as the branching points and endpoints in the vascular structure. Local clusters due to noise will result in several nearby branching points, from which the center voxel is used as the representing node. We then find the path between connected node pairs, decomposing the vascular structure into nodes and vessel segments. For each vessel segment, we use a restricted flood fill algorithm for refinement. We define a restricted area including both nodes and recalculate the height map of this area based on the vesselness values. A refined path between the node pair is generated by following the neighboring voxels with maximum delta height (like the path a flood runs down a hill). In this way, we are able to reconnect the break points in the vessels. To avoid the bias from nearby large vessels in refining paths of smaller vessels, we process the segments from the largest vessel to the smallest vessel, and mask out previous segments in the search region of later segments.

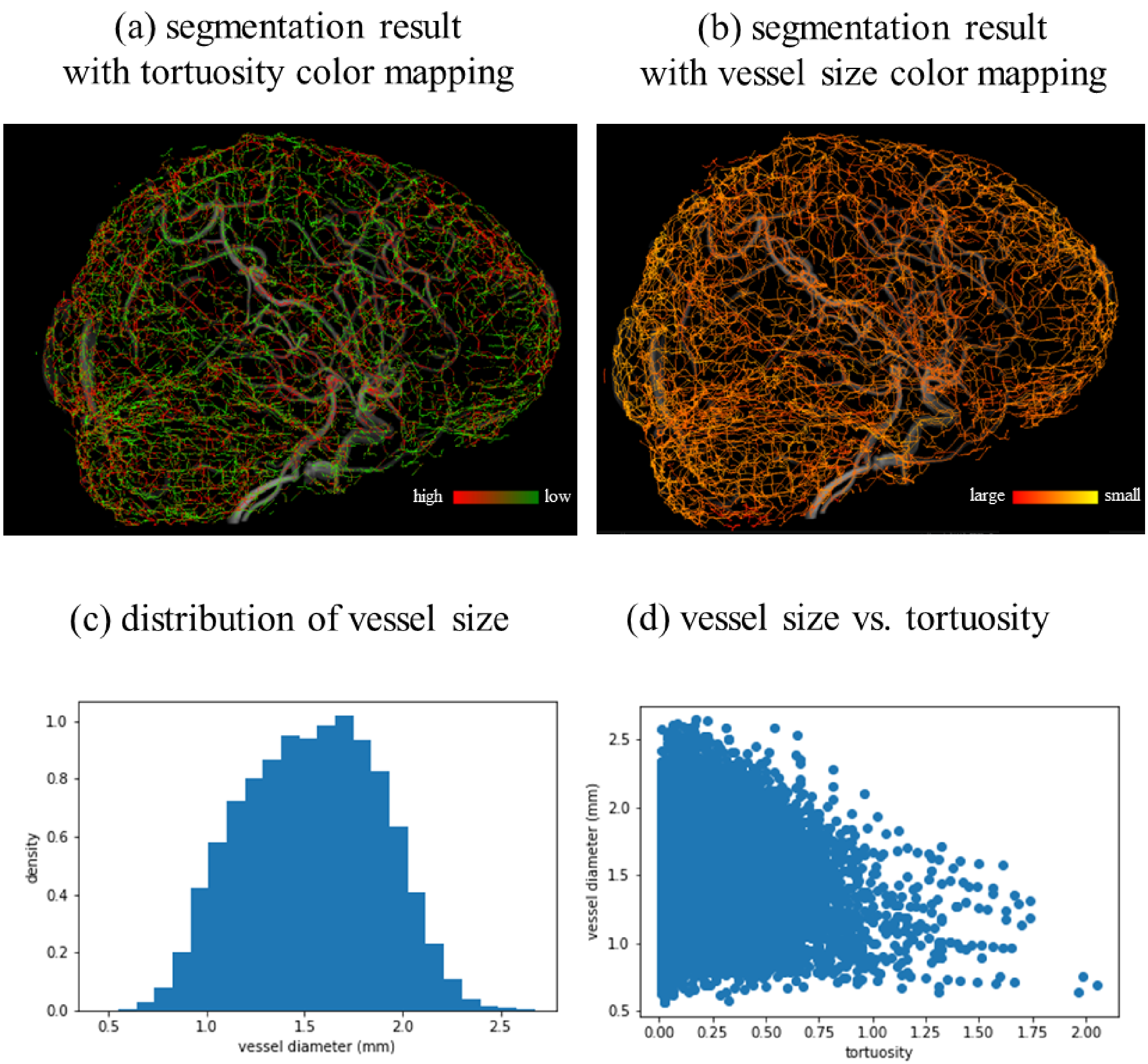
We then alternately refine the nodes and paths for several iterations: with refined paths we can remove false branching nodes, and with an updated set of nodes we can again refine the paths. Eventually the algorithm achieves an accurate estimate of the vessel medial axis, which is then used to compute important features of the vessels, such as diameter and tortuosity.



·Fig. 1 Flowchart of the algorithm

Results:

An example of the vessel segmentation result using VesselMapper on a TOF image is shown in Fig. 2. Specifically, Fig. 2 top panel shows the segmentation results colored by vessel tortuosity and vessel diameter. Fig. 2 bottom panel shows the histogram distribution of vessel diameter and the scatter plot of tortuosity and vessel diameter at each segmented voxel. Left-skewed unimodal distribution of vessel diameter fits the branching patterns of cerebrovasculature, with more small vessels than large vessels. Negative correlation between vessel size and tortuosity suggests that small vessels are more tortuous.



·Fig. 2 Segmentation result

Conclusions:

In this paper, we propose VesselMapper, a vessel segmentation algorithm for 3D images that is robust to noise. Using VesselMapper, we segmented the brain blood vessels in TOF images, and further calculated the morphological features of the vessels. This method can be used to detect subtle morphological changes of blood vessels in the brain in developmental, aging, disease or treatment-related cerebrovascular changes.

Modeling and Analysis Methods:

Methods Development
Segmentation and Parcellation [1]

Neuroanatomy, Physiology, Metabolism and Neurotransmission:

Anatomy and Functional Systems [2]

Keywords:

Cerebrovascular Disease
MR ANGIOGRAPHY
Segmentation

[1|2]Indicates the priority used for review

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No

Please indicate below if your study was a "resting state" or "task-activation” study.

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Please indicate which methods were used in your research:

Other, Please specify - MRA

For human MRI, what field strength scanner do you use?

7T

Which processing packages did you use for your study?

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Provide references using author date format

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