

Development of a Quantitative Intracranial Vascular Features Extraction Tool on 3D MRA Using Semiautomated Open-Curve Active Contour Vessel Tracing

Magnetic Resonance in Medicine

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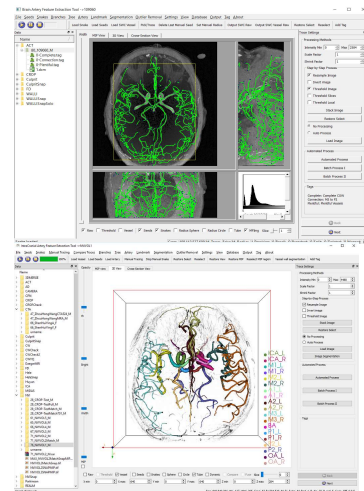
UNIVERSITY of WASHINGTON



Hi, I am Li Chen, from the Vascular imaging lab at the University of Washington. It is an honor for me to present our work which recently published in Magnetic Resonance in Medicine. The title is Development of a Quantitative Intracranial Vascular Features Extraction Tool on 3D MRA Using Semiautomated Open-Curve Active Contour Vessel Tracing

What is iCafe?

- > intraCranial artery feature extraction (iCafe)
- > From 3D MRA images to quantitative vascular map
 - Each artery reconstructed with radius varying tube
 - Each artery labeled with a certain type
- iCafe features: Comprehensive
 - Both morphometry and intensity features
 - 24 artery types => Region based analysis
- iCafe process: Semi-automated and supervised
 - Correct mistakes => Ensure accuracy
 - Easy human interventions



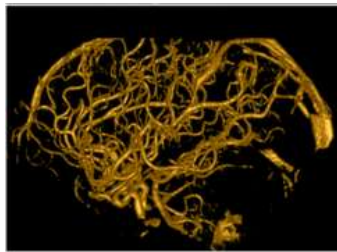
User interface of iCafe

iCafe processing demo available on YouTube: [#iCafe demo](#)

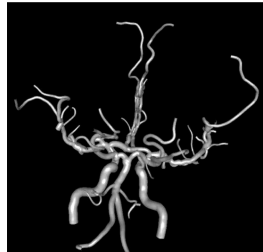


In this paper, we introduced the development of an intraCranial artery feature extraction tool, which we named iCafe. This tool uses image processing and machine learning techniques to convert 3D Time of Flight MRA images to a quantitative vascular map. In this map, each artery is reconstructed as a tubular structure with various radius, and labeled with its anatomical name, so that we can acquire comprehensive vascular features. The features provided by iCafe are comprehensive. For each artery, iCafe can not only calculate its morphometry features such as length and volume, it can also find intensity features such as mean artery intensity. As signal intensity is related to blood flow velocity in TOF MRA images, we believe the intensity features are also informative. In addition, each artery can be label as 24 artery types, so we can not only get global features, but also regional features. For example, tortuosity for left M3 segments of middle cerebral arteries can be defined. It (what??) is a complex network for human intracranial arteries. There are more than 200 branches, and most of them with diameter less than 1 millimeter. To ensure high accuracy for vasculature quantification, currently, iCafe processing is semi-automated. A human reviewer needs to supervise the process and correct mistakes based on automated results. A user friendly graphical interface and many handy operations are available for human to edit reconstructed artery traces with ease. You can have a look at our YouTube playlist for more details about iCafe processing.

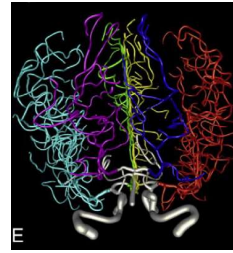
Why another intracranial artery tool is needed?



Segmentation only [1]



With limited correction ability [2]



Dividing into only six zones [3]



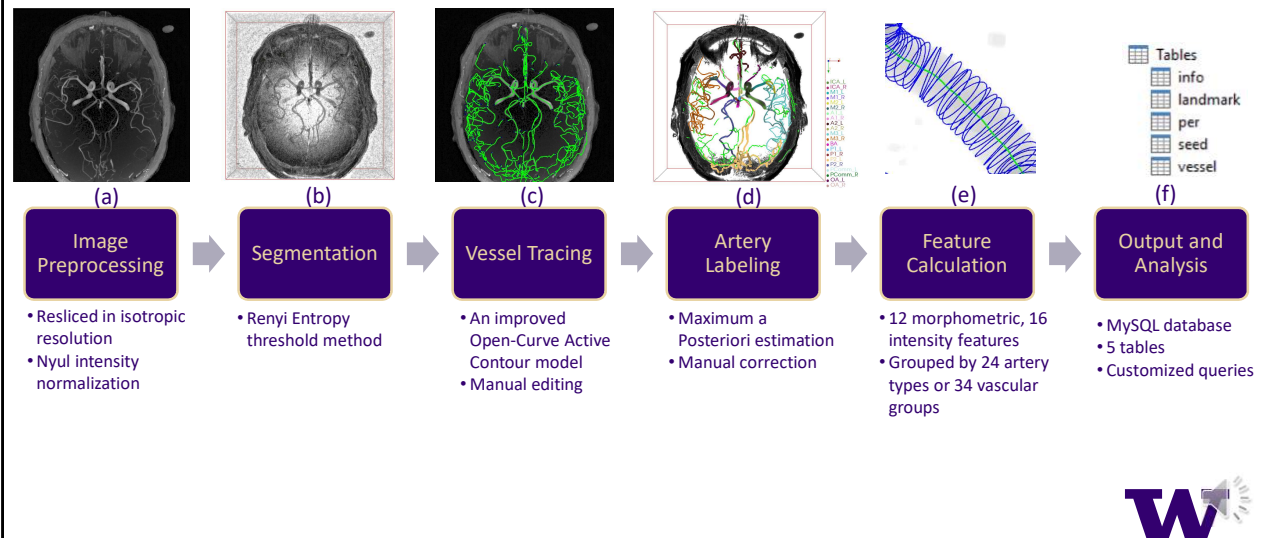
Taking long time in processing [4]

[1] Zhao, et.al, 2017, IEEE TMI [2] Volkau, et.al, 2005, IEEE TMI
[3] Wright, et.al, 2013, NeuroImage [4] Marchenko, et al, 2010, J of Digital Imaging



Some tools existed for intracranial artery analysis, but iCafe is different and special. First, iCafe is not just segmenting artery regions like many vessel filters, instead it traces arteries and reconstructs artery region into tubular shapes. By doing so, artery features can be easily quantified and visualized. Second, compared with many artery tracing tools, iCafe provides users with easy and plentiful operations to modify direction, position and radius of artery traces in a combination of views provided in iCafe. Reviewers can identify detailed regions clearly so that the vascular map generated can be of high quality. Third, 24 types of arteries in iCafe generated artery map can provide far more information than just dividing artery map into limited regions. Lastly, processing time needed for iCafe is reasonable. For each case, automated operations in iCafe needs about 3 minutes, human supervision takes 20 minutes to 1 hour depending on subjects. This is much shorter than some tools taking up to days.

Procedure of processing with iCafe

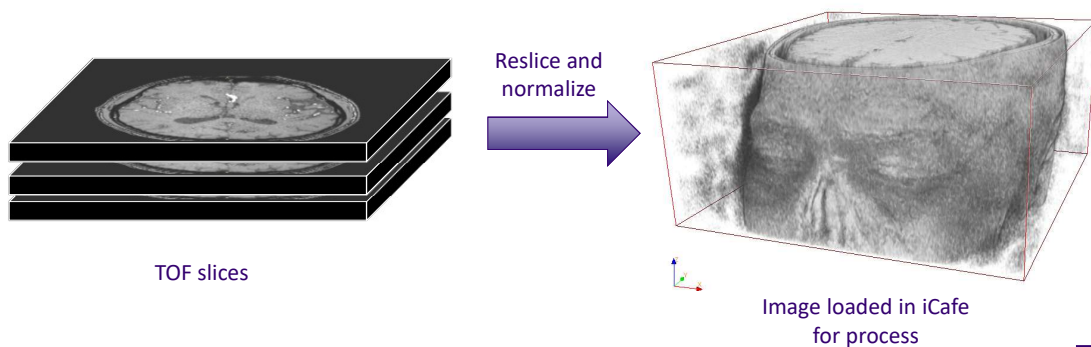


There are six main steps in the procedure for iCafe processing. Images are resliced and normalized (automatically??), then artery region is rudimentarily segmented to constrain artery regions. A tracing method is applied to find artery region and reconstructed into tubular structures. After that, labels for arteries are given and features for each artery are calculated. Artery features are well organized in a database. We can query global and regional features as required.

I will explain each step in details in the following slides.

Step1: Image Preprocessing

- > 3D TOF MRA resliced in isotropic resolution
- > Nyul [1] intensity normalization for comparable intensity among subjects



[1] Nyul, et.al, 2000, IEEE TMI

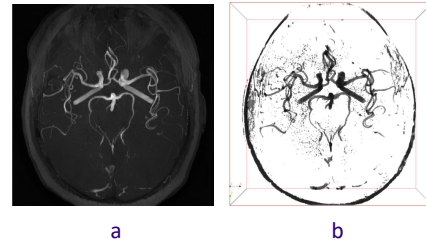


In this automated step, we used bicubic interpolation to reslice image slices into isotropic resolution, which is required for 3D space artery tracing.

As we know, the absolute intensity values of MR images do not have a fixed meaning. Thus, a fast and accurate intensity normalization method by Nyul (31) was used to adjust intensities among cases in the data- base. In this normalization method, based on the assumption that the histogram of each MRA image is similar, 11 intensity percentile points were used to adjust each intensity range to a mean histogram model.

Step2: Segmentation

- > Segmentation for clear visualization
 - Renyi entropy [1] threshold method



a: Original MRA image from MIP view
b: Renyi Entropy [1] thresholded image

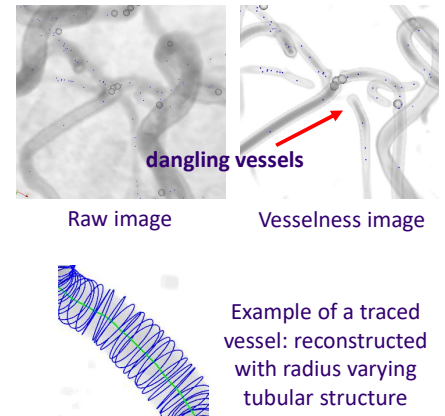
[1] J. N. Kapur, Comput. Vision, Graph. Image Process, 1985



Segmentation is needed for visualization in 3D view. The segmentation method is able to keep main artery structure and remove most noises. Renyi method was found to be efficient and successful.

Step3: Vessel Tracing

- > Frangi filter [1] to enhance vessel region
- > Open-curve active contour model [2]
 - Open-curve: no initial shape needed
 - Active contour: ensure smoothness and stretchiness
 - A two-step tracing improvement to solve dangling vessels
- > Human editing to ensure high quality
 - MIP/3D/Slice/Cross-sectional view to clearly see artery structures
 - Easy operations to merge/delete/split/modify traces



[1] Frangi, et.al, MICCAI, 1998

[2] Wang, et.al, Neuroinformatics, 2011

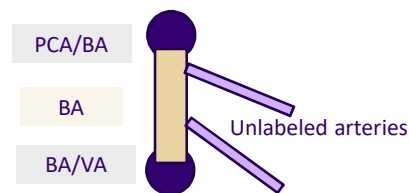


This is the most critical part of processing. First, Frangi filter was used to enhance vessel region and generate a vesselness image to assist tracing. An open-curve active contour model was used to trace artery region. This method was one of the active contour models. Through iterations, the contours can be smoothed and easy to stretch along artery region. Better than traditional acm, this open-curve improvement does not need a given initial contour. It stretches along the vesselness direction based on a single seed, which is easy to initialize. Based on the condition that Frangi filtered vesselness image does not have a clear artery shape near bifurcations, a .. is used.

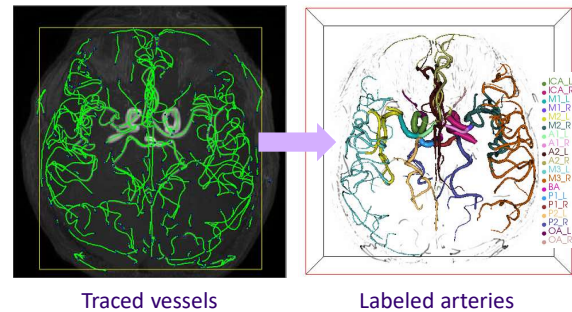
Human editing is needed to identify errors from the automated tracing. Mistakes include untraced arteries, broken arteries, wrong connections, traces on noise. They may be due to regional signal change, not enough contrast with background, too much noise.

Step4: Artery Labeling

- > Assigning landmark points with human assistance
- > iCafe defines artery by type of landmarks on both ends
 - 31 types of landmark points to define 24 types of arteries



Marking landmark points to define arteries

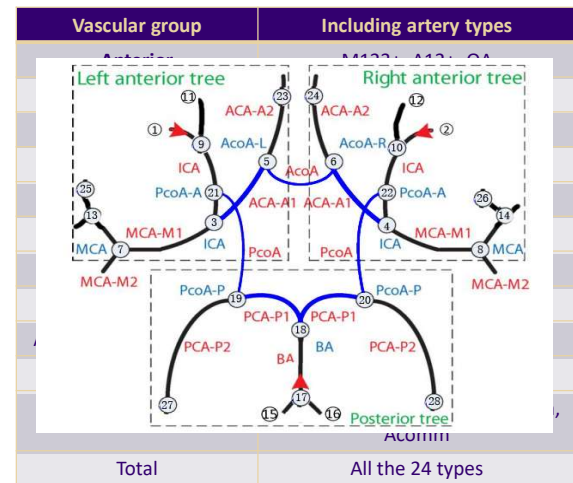


Considering small branches (without naming in iCafe) in the middle of arteries, and also anatomically many arteries are defined by bifurcations, add landmark to bifurcation instead of directly labeling arteries.

User selects a certain artery to mark its ending point. About 30 landmarks in 31 categories. iCafe automatically finds all arteries with given rules.

Step5: Feature Calculation

- > Feature calculation based on radius varying tubular structures
- > Each artery 12 morphometric features
 - Length, volume, tortuosity, etc.
- > Each artery 16 intensity features
 - Mean, max, variation, etc.
- > Further aggregated in vascular groups for regional features



Can be Total of: 1456 features

Artery anatomical structure image adapted from Bogunović, IEEE TMI, 2013



Features for each artery are calculated. Morphometry features are calculated using shape and direction of reco tubular structures. Intensity features are calculated based on centerline intensity of the artery. Then with different artery grouping methods, aggregated/regional features can be calculated.

Step6: Output and Analysis

- > iCafe results exported in a MySQL database for easier data management
- > 1,456 features for each case could be retrieved for analysis
- > Custom designed queries for additional features
 - Such as difference of length in left and right anterior proximal arteries in subjects with a complete CoW



iCafe can generate >1000 features for each subject. Only store ~20 features for each artery in MySQL database, and users can retrieve features based on request. Using database, it is also flexible to design additional features by writing new database queries.

Validation

- > 8 subjects for validation
- > Experienced neuroradiologists
 - marked position of bifurcations from 2D slices of MRA
 - marked position of stenosis points from 2D slices of MRA
 - Measured M1 segment length using Philips Intellispace Portal Software
- > Compare with iCafe result
 - iCafe detects bifurcations sensitivity of 94%, positive prediction value (PPV) of 85%, deviation distance of points was $0.33 \pm 0.44\text{mm}$
 - iCafe detects stenosis positions sensitivity 85%, PPV of 85%
 - Length measurement difference 3.15%, intraclass correlation coefficient of the two measurements 0.97



In order to validate traces are correct and measurements are reliable, three val were performed

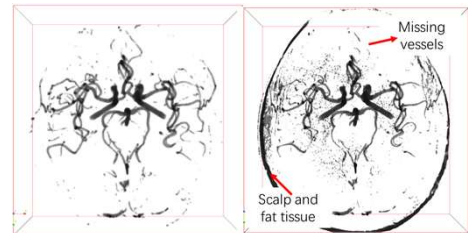
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The comparison results showed that

iCafe length measurements are very close to measurements from Philips workstation with strong correlation

Advances using machine learning

- > Deep learning (Y-net) [1] for better artery area segmentation
 - Train from iCafe processed images
- > A machine learning algorithm [2] to predict landmark type
 - Using positional, directional and structural features



Left: Segmentation from Y-net
Right: Segmentation from traditional method [3]

[1] Chen, et.al, arXiv, 2017

[2] Chen, et.al, RSNA, 2017

[3] J. N. Kapur, Comput. Vision, Graph. Image Process, 1985

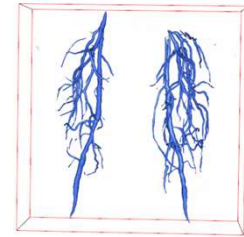


iCafe is actively integrating more machine learning components to facilitate its process. Previously processed cases can be training labels to allow easier and faster future process. One improvement is on seg for visualization. Using reconstructed traces as lumen labels, train a Y-net to segment artery region. Better than previous method using traditional img processing method.

Another improvement is giving landmark prediction based on pos, dir, and stru features. Save time for choosing labels.

More components expected

- [illegible]

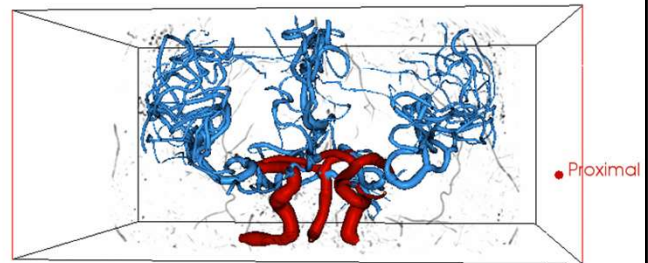


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Summary

- > iCafe is a tool for comprehensive and quantitative analysis of intracranial artery features
- > Automated tracing + human supervision to ensure high quality vascular map
- > Facilitate research and clinical application where artery measurement and/or visualization are needed



3D animation of a healthy subject using iCafe



Distal



Acknowledgement

- > The following lab members provided assistance
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