Development of a Quantitative Assessment tool for Peripheral Artery Feature Extraction (pCafe)

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Synopsis

Peripheral artery disease is a relatively common disease, normally caused by reduced blood flow to the limbs due to atherosclerosis in the arteries supplying them. Peripheral arteries' anatomy, including collateral circulation, and flow information enable disease status assessment. We developed pCafe to semi-automatically trace peripheral arteries from 3D magnetic resonance angiography and measure both morphometry (anatomy) and intensity features (velocity). pCafe was validated on subjects with, and without peripheral artery occlusion, showing excellent agreement with human reviewer's measurement (intra-class coefficient of 0.998). pCafe may be a useful tool to quantitatively characterize peripheral vascular structures in peripheral artery disease research.

INTRODUCTION

Peripheral artery disease (PAD) is a relatively common disease due to reduced blood flow to the limbs. PAD caused by atherosclerosis affects more than 200 million persons worldwide, and these patients are at a significantly higher risk of myocardial infarction, cardiovascular events and amputation[1,2]. The physiological adaptations to restore blood flow to occluded regions include increasing the diameter and the number of vessels within the collateral blood vessel circuit[2,3]. To fully evaluate and monitor PAD status and progression, it is important to conduct quantitative assessment of peripheral arteries, including collateral arteries. Current techniques to assess the severity of PAD in the lower limbs are focused on arterial pressure[4,5], blood flow[6], and the degree of stenosis[7] of the larger arteries, but a comprehensive quantification of structural features of the peripheral arterial circulation is lacking.

Therefore the aim of this study is to develop a peripheral artery feature extraction (pCafe) technique[8] to quantitatively assess the morphometry and intensity features of the peripheral vasculature using 3D contrast enhanced (CE) magnetic resonance angiography (MRA).

METHODS

MR imaging

Two subjects with peripheral artery disease were scanned using a 3.0T Philips (Best, The Netherlands) Ingenia CX MR scanner using torso phased array coil covering the legs. Study procedures followed local IRB guidelines and informed consent was obtained for all subjects. After single dose Prohance injection, single station first pass 3D CE-MRA was obtained covering the lower part of the thigh and knees bilaterally. Imaging parameters were as follows: TR/TE = 4.56/2.195 ms, flip angle = 20°, in-plane resolution = 0.81 mm×0.81 mm, slice thickness = 3 mm, field of view = 430 mm*430 mm.

Feature extraction

MRA images were resampled to isotropic resolution of 0.81 mm in 3D space and image intensities were normalized using the Nyul[9] method to allow comparable intensity features from different cases in the dataset. Artery regions were then automatically traced and reconstructed using an improved open-curve active contour model[10]. Several key landmark points need to be added manually so that all the arteries can be labeled as one of the following peripheral artery types: superficial femoral artery (SFA), profunda femoris artery (PFA) and their collateral arteries, both left and right. In the case of occluded SFA, collateral arteries can be further labeled as SFA collateral arteries proximal and distal to the occluded region (labeled upper and lower collaterals, respectively). An experienced vascular surgeon supervised the tracing and labeling process and corrections were made when needed.

A group of representative features (listed in Table 1) reflecting typical PAD arterial characteristics can be quantified using pCafe.

Validation

An experienced human reviewer measured SFA/PFA length using Philips Intellispace Portal Software (Philips Healthcare, Best, the Netherlands) to indirectly validate the accuracy of traces and vessel length measurements. Reference vessel length was measured by manually selecting centerline points along the arteries. After the centerline was drawn, length was measured on the corresponding curved planar reformatted image and compared to the length measurements using pCafe.

RESULTS

Original maximum intensity projection images, along with reconstructed collateral arteries using pCafe from subjects with and without occluded SFA are shown in Figure 1 and Figure 2, respectively.

A group of representative features extracted from pCafe for the subject with peripheral artery occlusion (subject 1) and the subject without occluded SFA (subject 2) is shown in Table 2.

The pCafe-measured length of eight arteries (both sides of SFA and PFA for two subjects) is in agreement with the reviewer-measured length. The mean absolute difference of the artery length is 6.24mm, and the intra-class coefficient is 0.998. A plot with the arterial length measurements is shown in Figure 3.

DISCUSSION

pCafe was shown to reconstruct peripheral arteries and extract features from subjects with and without SFA occlusions. Fourteen representative features were shown in this study, but with all peripheral arteries reconstructed, new custom features can be designed and added as needed. The quantitative information provided by pCafe is promising for a comprehensive description of peripheral artery status.

We used a human operator to verify pCafe artery tracings, as small arteries may be incorrectly connected due to the relatively weak signal intensity. Further improvement of pCafe is ongoing to reduce human input.

The validation of collateral arteries and radius of peripheral arteries is currently difficult to achieve, as it is challenging for human reviewers to segment and trace all the arteries in 2D image slices. To further validation, a reproducibility study on a larger study cohort is needed in the future.

CONCLUSION

A semi-automated quantitative measurement tool for peripheral arteries based on 3D CE MRA has been developed and may provide a novel set of vascular features for assessing PAD status and development.

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Figures

Features name	Feature definition
Total Length	Combined length of all the peripheral arteries visualized in the 3D MRA acquisition.
Total Volume	Volume of all the peripheral arteries that are visualized in the 3D acquisition. This calculation is based on the cylinder model with varying radius along the centerline.
SFA Radius	Average radius of both left and right Superficial Femoral arteries.
PFA Radius	Average radius of both left and right Profunda Femoris arteries.
Collateral SFA/PFA Length	Length of all collateral arteries originated from SFA or PFA.
Left/Right Collateral SFA/PFA Space	The minimum rectangular box area encompasses all Left/Right Collateral SFA/PFA arteries.
Left/Right Collateral SFA/PFA Density	The ratio of Volume to Space for Left/Right Collateral SFA/PFA arteries.
Collateral Branches	Number of all traces labeled as collateral arteries. Traces start from a bifurcation and end in another bifurcation or termination.
Total Branches	Number of all traces.
A_NormIntensity	Average signal intensity of each centerline point along all arteries after image normalization.
A_Tortuosity	Average *tortuosity* of all peripheral arteries. *Tortuosity* is defined as the ratio between artery length and the Euclidean distance of the two terminal points of an individual artery segment.

Table 1 Representative features available in pCafe

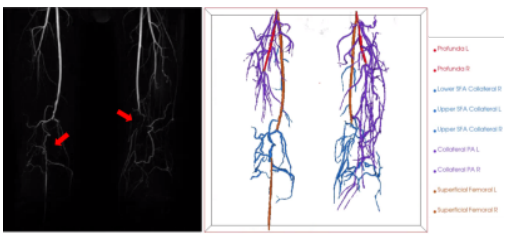

Figure 1 Maximum intensity projection of original CE-MRA image (left) and 3D pCAFE visualization (right) of traced arteries for a subject with bilateral superficial femoral artery total occlusion (pointed by red arrows)

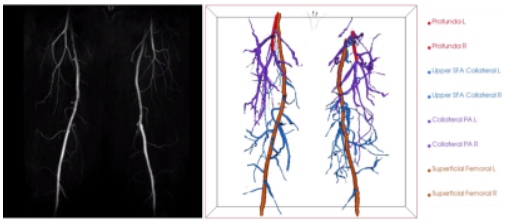

Figure 2 Maximum intensity projection of original CE-MRA image (left) and 3D pCAFE visualization (right) of traced arteries for a subject without arterial occlusion

	Subject 1	Subject 2
Total Length (mm)	8544.18	9664.21
Total Volume (*10³ mm³)	56.45	123.26
SFA Radius (mm)	2.43	4.15
PFA Radius (mm)	2.31	3.39
Collateral SFA Length (mm)	2072.30	4594.35
Collateral PFA Length (mm)	5648.49	4066.56
Collateral Branches	263	246
Total Branches	268	250
A_NormIntensity	691.02	588.27
A_Tortuosity	1.12	1.16
Left/Right Collateral PFA Space (*10³ mm³)	975.02/869.77	4662.03/4863.79
Left/Right Collateral PFA Density (*10⁻³ mm³)	7.77/3.74	3.85/3.05
Left/Right Upper SFA Collateral Space (*10³ mm³)	2254.45/2364.93	2827.39/2757.46
Left/Right Upper SFA Collateral Density (*10⁻³ mm³)	3.36/1.37	6.35/5.38

Table 2 Representative features quantified for two subjects using pCafe

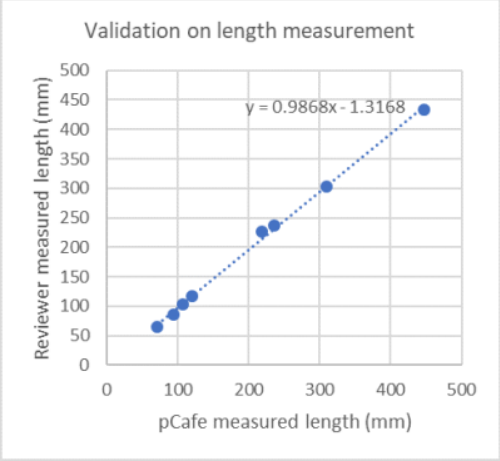

Figure 3 Plot of length measurement of SFA/PA by pCafe and human reviewer.