Artery-Vein Segmentation in Non-Contrast-Enhanced Flow-Independent 3D Peripheral Angiography

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Target Audience: MR physicists and clinicians interested in peripheral MR angiography or MR image segmentation.

Purpose: Magnetization-prepared 3D SSFP sequences have shown promise for non-contrast-enhanced flow-independent angiography (FIA) [1], where intrinsic tissue parameters such as T1, T2, and chemical shifts are exploited to generate stable vessel contrast even under slow flow conditions. However, an important challenge with this approach is sufficient artery-vein contrast, which is crucial for artery visualization and the diagnosis of arterial disease. Image processing algorithms have the potential to address this issue, particularly for deep veins such as the femoral veins that intertwine with femoral arteries in the lower extremities. Prior work on artery-vein segmentation[2,3] have required human supervision and were designed for contrast-enhanced MRA. In this work, we investigate unsupervised artery-vein segmentation for FIA, and use the Maximally Stable Extremal Regions (MSER) detector[4], which is particularly suited for intensity-based detection, to take advantage of the brighter arterial signal resulting from the T2 preparation used in the FIA sequence. We propose a method that combines the MSER detector with k-means clustering to perform fully unsupervised segmentation and removal of the femoral veins in 3D FIA datasets of the lower extremities.

Methods: Segmentation Algorithm: The femoral artery in each leg was tracked through all axial slices, and segmentation was performed around the arterial region in each slice. The initial seed point for tracking was determined by (1) computing MSER regions for a predetermined, uniform sampling of slices; (2) filtering by intensity, size, and shape to obtain candidate artery regions for the seed point; and (3) using a majority voting scheme to choose a final candidate that was consistent with location constraints (the location of the artery in nearby slices should change smoothly). Once an initial seed point, if any, was selected, the femoral artery was tracked up and down through the slices starting from this point. At each slice, k-means clustering was applied to segment a fixed-size window of pixels centered at the seed point (Fig. 1a). The features used to cluster each pixel were: a patch of intensity values around the pixel (Fig. 1b), a weighted distance of the pixel from the artery location in the previous slice (Fig. 1c), and a weighted distance of the pixel from the vein location in the previous slice (Fig. 1d). k=3 clusters corresponding to artery, vein, and muscle were used (Fig. 1e), and the artery and vein regions were determined from these clusters by intensity and location priors. Finally, morphological operations were used to clean up the vein region, and a mask operation was used to remove the vein from the slice (Fig. 1f). The centroid of the detected artery region and additional MSER detection was used to determine the seed point for the fixed-size window in the subsequent slice, and the process of k-means clustering and vein removal was repeated for each subsequent slice in the 3D dataset. If unstable clustering occurred for an extended number of slices, indicating that either the artery or vein was no longer detected, the algorithm would terminate before reaching all slices. A summary of the segmentation pipeline is shown in Fig. 1.

Imaging Parameters: In vivo experiments on 7 healthy volunteers and 1 patient with stenosis were performed on a GE Excite 1.5 T scanner with an 8 channel cardiac coil. The magnetization-prepared 3D SSFP sequence was designed to provide isotropic resolution = 1.2 mm and FOV = 34x34x30 cm³ (matrix size = 288x288x250). TE/TR = 2.5/6.0 ms, and flip angle = 70°. Total scan time was eight minutes. Images were reconstructed with 3D gridding followed by a factor of two zero-padding in all three dimensions for improved visualization. Segmentation and removal of the femoral veins were performed on the zero-padded images and the final images were shown as a coronal maximum-intensity-projection (MIP).

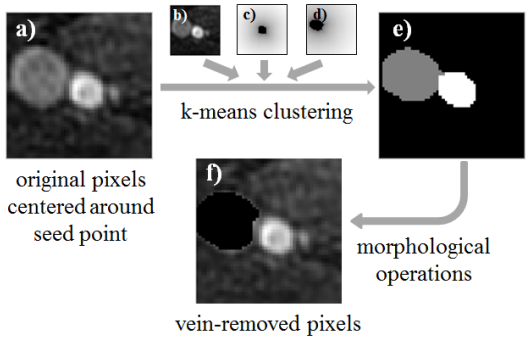

Fig. 1. Segmentation pipeline. (a) Fixed-size window of original pixels centered around seed point in a slice. Seed point is obtained from previous slice and/or MSER detector. (b),(c),(d) Feature inputs to k-means clustering: pixel intensities, weighted distance from previous slice artery, and weighted distance from previous slice vein, respectively. (e) k-means clusters corresponding to artery (white), vein (gray), and muscle (black). (f) Final pixels with vein removed.

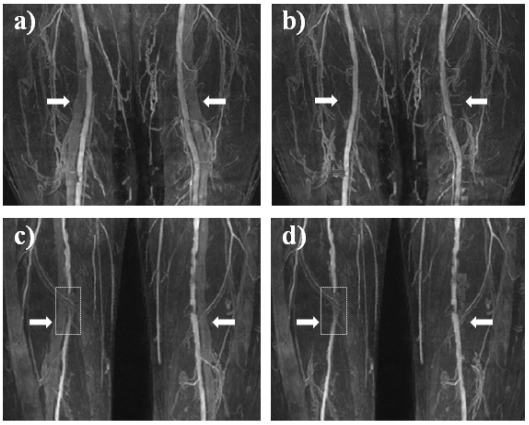

Fig. 2. Coronal MIPs of (a,b) a healthy volunteer and (c,d) a patient. (a) and (c) are before vein removal; (b) and (d) are after. Arrows indicate location of femoral vein. Dashed box shows a region of stenosis.

Results: Of the 16 legs from 8 scans, an initial seed point corresponding to the femoral artery was correctly determined in 13 legs (81.3%). Overall, the algorithm successfully removed the femoral veins in 68.0% of the slices where veins were present, totaled over these 13 legs. The femoral arteries were fully preserved in 99.6% of the slices, and appear as an obvious artifact (a dark line cutting across the artery in the MIP image) in the other 0.04%. For all slices where k-means clustering was performed (i.e., excluding slices that were not reached due to early termination from unstable clustering), a confusion matrix summarizing total clustering accuracy is shown in Table 1. Coronal MIPs of two datasets before and after vein removal are shown in Fig. 2.

		Predicted		
		Artery	Vein	Muscle
Actual	Artery	0.99	0.01	0.00
	Vein	0.06	0.86	0.08
	Muscle	0.01	0.04	0.95

Table 1. Confusion matrix for k-means clustering of artery, vein, and muscle.

Discussion and Conclusion: We demonstrated the feasibility of an image processing algorithm to improve artery-vein contrast in FIA of the lower extremities by vein segmentation and removal. Fig. 2 shows the improved artery visualization achieved through this method. The algorithm may also be adapted for contrast-enhanced MRA and other applications where artery-vein discrimination is an issue. Identified areas for further work include incorporating additional location features to improve clustering performance when the artery, vein, and/or muscle are similar in intensity, and testing the algorithm on more patient data.

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