Fast plaque burden assessment of the femoral artery using 3D black-blood MRI and automated segmentation

B. Chiu[1], X. Zhao[1], J. Wang[2], N. Balu[1], C. Yuan[1], and W. S. Kerwin[1]
[1]Radiology, University of Washington, Seattle, Washington, United States, [2]Clinical Sites Research Program, Philips Research North America, Briarcliff Manor, New York, United States

Introduction With its prevalence projected at about 27 millions people in Europe and North America, peripheral arterial disease (PAD) has become a serious health issue in the western world [1]. In addition to the risk of limb ischemia, which may eventually lead to amputation, PAD is associated with an elevated risk of cardiovascular and cerebrovascular events [1]. Recent advances in high-resolution MRI have allowed noninvasive and detailed assessment of PAD, including black-blood MRI visualization of the vessel wall. While vessel wall MRI affords the opportunity to investigate the size, shape and composition of the vessel wall, the length of a femoral artery is substantial, leading to a long field of view required to image the whole femoral artery. Because manual outlining of wall boundaries along the entire length of the femoral artery is an arduous task, this work focuses on developing an accurate segmentation algorithm that requires minimal user input, in order to allow efficient plaque burden quantification of the femoral artery.

Methods The MR images were acquired in the coronal plane with the iMSDE prepared 3D MERGE black-blood sequence, which applies a prepulse to suppress moving spins in blood [2]. The iMSDE preparation used a gradient strength 25 mT/m and gradient duration 0.675ms, with additional imaging parameters: TR/TE 10/4.8ms, FA 6°, TFE factor 100, and fat saturation. Multiple stations with FOV 250×400×40mm were used to cover over 500mm with isotropic voxel size of 1.0×1.0×1.0mm (reconstructed to 0.5×0.5×0.5mm).. The imaging volumes were fused and resliced into the axial plane, producing on the order of 1000 images per subject. Total scan time was 7-10mins.

To extract the lumen boundary in all cross-sections, the boundary on the first image in the stack was manually identified. This boundary was then propagated through all images in the stack by iteratively registering each subsequent image with the prior one using an optical flow registration algorithm. After each registration, the previous lumen boundary was transformed according to this registration result and used as the initial contour on the subsequent image, which was optimized using a B-spline snake algorithm [3]. After propagating the lumen through the entire stack, the wall boundary was found in each image. This algorithm used a conditional shape model [4] to initialize a contour, which was optimized by the snake algorithm. The final shape of the wall boundaries was also constrained by the conditional shape model.

To validate the segmentation results, an expert observer manually segmented every tenth image in a femoral artery MR set. The lumen boundary on the first image was used to initialize the propagation algorithm. The wall and lumen boundaries segmented by the proposed algorithm were compared with the manually segmented boundaries using two distance-based metrics, mean absolute difference (MAD) and maximum difference (MAXD), and two area-based metrics, area overlap (AO) and area difference (AD), as described in [5].

	MAD (mm)	MAXD (mm)	Mean AO (%)	Mean AD (%)
Lumen	0.169	1.02	87.5	6.56
Wall	0.279	2.37	87.1	11.5

Table 1 MAD, MAXD, mean AO and AD for the whole artery.

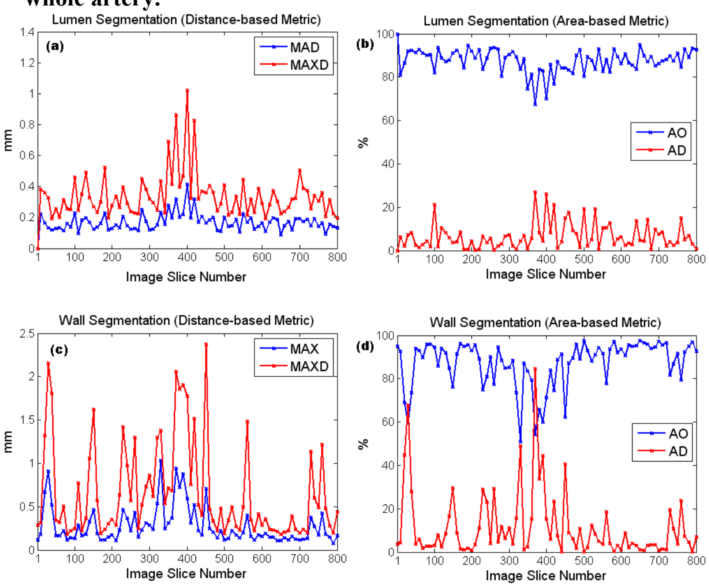

Fig. 3 MAD, MAXD, AO and AD of the lumen and wall segmentations for 81 images that were manually segmented

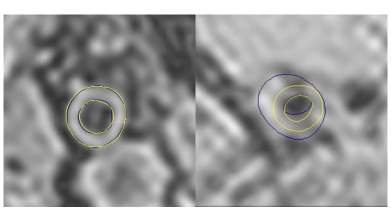

Fig. 2 Segmentation accuracy for Image 80 and 370. Manually outlined contours are colored in yellow, and contours segmented by our algorithm in blue.

Results The segmentation of the lumen and the outer wall on 800 images took 102s and 162s respectively, whereas it took about 1hr to manually segment 80 images. Fig. 1(a) shows the MAD and MAXD, and Fig. 1(b) shows the AO and AD associated with the lumen boundaries in each image slice. Fig. 1(c) shows the MAD and MAXD, and Fig. 1(d) shows the AO and AD associated with the wall boundaries. Table 1 shows the results for the whole artery. Fig. 2 shows two cross-sectional images with manual and semi-automatic segmentations superimposed. Fig. 2(a) shows Image Slice 80 and Fig 2(b) shows Image Slice 370 (see Fig. 1 for distance- and area-metrics of these two images). The wall boundary is poorly defined in Fig. 2(b) because the artery is surrounded by muscular tissues, which have a similar intensity to the vessel wall. The poor definition of the lumen boundary in Fig. 2(b) may be attributed to inadequate blood-suppression during MRI acquisition and the obliqueness of the artery with respect to the acquisition plane.

Discussion and Conclusion With the advent of fast 3D high-resolution MR imaging, it is now possible to image the whole femoral artery with sub-millimeter resolution in a few minutes. Developing a framework to analyze such huge image sets efficiently is the necessary next leap to enable this technology to be used in the management of PAD. Here, we proposed and demonstrated a dedicated automatic segmentation algorithm capable of accurately identifying the lumen and wall boundaries along the majority of the femoral artery. There are two future directions that could be taken to further improve the segmentation efficiency. The first is to propagate the contours in different orientations and introduce a scheme to select an "optimum" boundary as was done in [6]. The second is to develop a user-friendly visualization and editing tool that will allow easy editing of the contours in problematic images.

Reference [1] Belch et al., Arch Intern Med, 2003: 884-892. [2] Balu et al., Proc. of ISMRM: 3021. [3] Kerwin et al., TMRI 2007: 371-378. [4] Underhill et al., Proc. of ISMRM 2006: 829. [5] Chiu et al., Phys. Med. Biol. 2004, 4943-4960. [6] Ding et al., Med. Phys. 2007: 4109-4125.