Fast, Reliable Carotid Plaque Burden Measurements with Interactive Snakes

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Introduction

Atherosclerosis is a leading cause of heart attacks and strokes worldwide. Considerable interest exists in using MRI of carotid atherosclerosis to measure plaque burden as a possible risk factor for stroke, as a systemic marker of overall atherosclerosis, or in clinical trials to monitor drug response. To measure plaque burden, inner and outer wall boundaries must be identified in serial cross sectional MRI of the carotid artery. While several automated tools for artery boundary detection have been proposed, their frequent failure has led to most plaque burden assessments being performed manually. The purpose of this investigation was to develop an overall system for wall boundary detection featuring reliable automated tools, and rapid, interactive, and flexible adjustment of the detection results as needed.

Methods

Inner and outer wall boundary detection was performed on black-blood T1-weighted cross sectional images at 10 locations spanning the carotid artery bifurcation at 2 mm intervals (Double inversion recovery fast spin echo sequence with TR=800ms, TE=9.4ms, TI=350ms, FOV=16x12 cm, matrix=256x192). The images were loaded into the Pathway Carotid Analysis Package (PCAP, Pathway MRI, Seattle) for analysis, which served as the interface for the boundary detection procedure. Inner boundary detection was performed by the user providing a single point in the lumen, which identified the lumen region from a mean-shift segmentation of the region of interest [1]. The boundary of this region was then fed to a B-spline snake [2] that refined the boundary based on local image gradients. Outer wall boundaries were identified by assuming plaque thickness remained similar in adjacent locations and initializing a B-spline snake at thicknesses ranging from 0.5 to 1.5 times the previous thickness. The overall best fit was selected. For both boundaries, two interactive adjustments were incorporated. First, a slider bar was used to manually adjust the expected lumen size for inner boundary detection and to vary the thickness parameter, which permits the user to rapidly step through alternate solutions. Additionally, the B-spline formulation of the snake enabled the user to make further manual edits by adjusting the node points of the spline. The real-time interaction of the user led us to refer to this environment as interatctive snakes (I-snakes). In practice, the user steps through from proximal to distal cross sections, interactively identifying the inner boundary and then the outer boundary at successive locations. Performance of this approach was assessed by measuring reproducibility in six subjects with 16-49% carotid stenosis imaged at 1-week intervals.

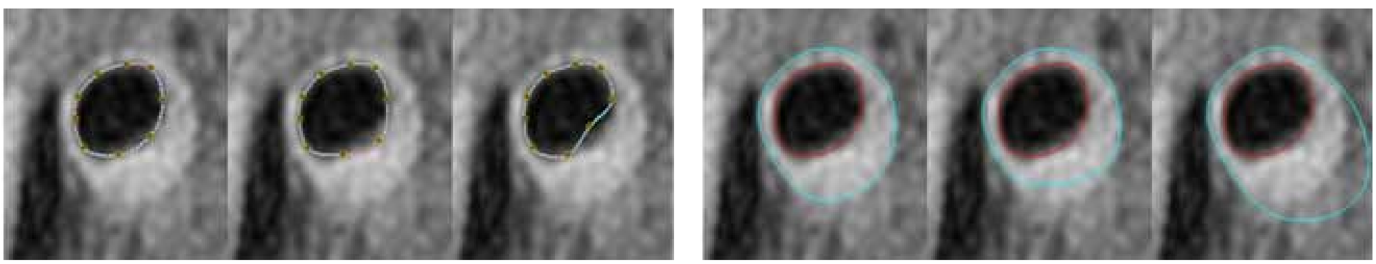

Figure 1. Illustration of lumen detection (left) showing original result (leftmost) and adjustment of spline nodes, and wall detection (right) showing original result (leftmost) and adjustment of thickness parameter.

Results

One reviewer performed plaque burden analysis at both time points and a second reviewer conducted analysis at the first time point for a total of 18 analyses. The average time per artery for inner and outer boundary identification with I-Snakes was under two minutes. In a previous analysis, the first reviewer had used manual outlining to identify the boundaries at both time points. The resulting scan-to-scan coefficients of variation are stated in Table 1 for manual and automated review. Additionally, the inter-rater coefficients of variation were 4.1% for lumen volume and 4.3% for wall volume. Significant improvements in the coefficients of variation were observed when using I-snakes.

Conclusions

The I-Snakes environment provides a rapid tool for identifying inner and outer wall boundaries in MRI of the carotid arteries. The ability to sequence through alternate solutions in real time greatly accelerates the analysis of carotid plaque burden. Additionally, the dependence of I-Snakes on actual image features rather than features perceived by the reviewer improves the reproducibility of burden measurements.

Table 1. Coefficients of variation for lumen/wall volumes

	Manual	I-Snakes
Lumen Volume	4.9%	3.7%
Wall Volume	8.2%	4.9%

References

[1] Fukunaga & Hostetler. *IEEE Trans. Inf. Theory*, 21:32–40, 1975

[2] Bigger & Unser *IEEE Trans Image Processing,* 9:1484-96, 2000.