PhD Thesis title: 'Vascular Segmentation Algorithms for Generating 3D Atherosclerotic Measurements'

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ABSTRACT:
Atherosclerosis manifests as plaques within large arteries of the body and remains as a leading cause of mortality and morbidity in the world. Major cardiovascular events may occur in patients without known pre-existing symptoms, thus it is important to monitor progression and regression of the plaque burden in the arteries for evaluating patient's response to therapy. In this dissertation, our main focus is quantification of plaque burden from the carotid and femoral arteries, which are major sites for plaque formation, and are straight forward to image noninvasively due to their superficial location. Recently, 3D measurements of plaque burden have shown to be more sensitive to the changes of plaque burden than one-/two-dimensional measurements. However, despite the advancements of 3D non-invasive imaging technology with rapid acquisition capabilities, and the high sensitivity of the 3D plaque measurements of plaque burden, they are still not widely used due to the inordinate amount of time and effort required to delineate artery walls plus plaque boundaries to obtain 3D measurements from the images. Therefore, the objective of this dissertation is developing novel semi-automated segmentation methods to alleviate measurement burden from the observer for segmentation of the outer wall and lumen boundaries from: (1) 3D carotid ultrasound (US) images, (2) 3D carotid black-blood magnetic resonance (MR) images, and (3) 3D femoral black-blood MR images. Segmentation of the carotid lumen and outer wall from 3DUS images is a challenging task due to low image contrast, for which no method has been previously reported. Initially, we developed a 2D slice-wise segmentation algorithm based on the level set method, which was then extended to 3D. The 3D algorithm required fewer user interactions than manual delineation and the 2D method. The algorithm reduced user time by ≈79% (1.72 *vs.* 8.3 min) compared to manual segmentation for generating 3D-based measurements with high accuracy (Dice similarity coefficient (DSC)>90%). Secondly, we developed a novel 3D multi-region segmentation algorithm, which simultaneously delineates both the carotid lumen and outer wall surfaces from MR images by evolving two coupled surfaces using a convex max-flow-based technique. The algorithm required user interaction only on a single transverse slice of the 3D image for generating 3D surfaces of the lumen and outer wall. The algorithm was parallelized using graphics processing units (GPU) to increase computational speed, thus reducing user time by 93% (0.78 *vs.* 12 min) compared to manual segmentation. Moreover, the algorithm yielded high accuracy (DSC > 90%) and high precision (intra-observer CV < 5.6% and inter-observer CV < 6.6%). Finally, we developed and validated an algorithm based on convex max-flow formulation to segment the femoral arteries that enforces a tubular shape prior and an inter-surface consistency of the outer wall and lumen to maintain a minimum separation distance between the two surfaces. The algorithm required the observer to choose only about 11 points on its medial axis of the artery to yield the 3D surfaces of the lumen and outer wall, which reduced the operator time by 97% (1.8 *vs.* 70-80 min) compared to manual segmentation. Furthermore, the proposed algorithm reported DSC greater than 85% and small intra-observer variability (CV ≈ 6.69%). In conclusion, the development of robust semi-automated algorithms for generating 3D measurements of plaque burden may accelerate translation of 3D measurements to clinical trials and subsequently to clinical care.

References to author publications that relate specifically to the dissertation:

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