Abstract

Stroke is an interruption of blood to any part of the brain. It is the fourth leading cause of death in the USA. Rupture of atherosclerotic plaques in the carotid artery has been implicated in 20% of strokes. Currently, severity of plaques is assessed by measuring the velocity of blood flow through the stenosed artery using Doppler ultrasound. However, imaging and monitoring plaque progression in 3D can better classify disease severity and potentially identify plaque vulnerability to rupture. Vessel wall volume (VWV) has been proposed as a 3D measurement of arterial wall and plaque burden. It is defined as the enclosed volume between the adventitial wall boundary (AWB) and the lumen-intima boundary (LIB). A computer-based algorithm for the segmentation of LIB and AWB will accelerate the translation of VWV of carotid atherosclerosis to clinical research and clinical practice. The goal of this thesis is to develop semi-automatic 2D and 3D segmentation algorithms for segmenting LIB and AWB of the carotid artery from proximal common carotid to distal internal and external carotid artery.

Our proposed segmentation algorithm uses distance regularized level set method with edge-based energy, region-based energy, smoothness energy, and a novel stopping criteria to segment LIB and AWB of carotid artery from 3D US images. 3D US images were acquired from patients with asymptomatic carotid plaques as part of an ongoing clinical study. The data set consists of 210 2D cross-sectional slices selected from 10 3D US patient images at an inter-slice distance of 1mm. Manual initialization at an inter slice distance of 4mm was used. To stop the leaking of evolving contour through the poor boundary contrast regions, we defined a stopping boundary (2D algorithm) or surface (3D algorithm) based energy. To save computational time, change of modified Hausdorff distance (MHD) between evolving contours at successive iterations (2D algorithm) or percentage change of pixel locations (3D algorithm) was used as stopping criteria along with stopping boundary or surface based energy. Due to the absence of clinical ground truth boundary, an average curve was generated from manually segmented boundaries by three observers. The average curve was used as a ground truth boundary and algorithm generated boundary was compared against it. The error metrics are dice similarity coefficient (DSC), Hausdorff distance (HD), and MHD.

The proposed stopping criteria were compared with other two conventional stopping criteria: percentage change of area inside evolving contours and change of MHD between evolving contours at successive iterations. The performance of the proposed algorithm was better than other two stopping criteria and yielded mean of: LIB_{DSC} = 88.78\%, AWB_{DSC} = 94.81\%, LIB_{MHD}=0.26 mm, AWB_{MHD}=0.25 mm, LIB_{HD}=0.74 mm, AWB_{HD}=0.80 mm. The Bland-Altman plot and correlation coefficient (r=0.99) indicated a high agreement between ground truth boundaries and algorithm generated boundaries. The minimum detectable change of VWV by the proposed algorithm is 161 mm$^3$. The overall execution time
to segment whole volume is 40 ± 5 min and 100 ± 5 min for algorithm and manual observers respectively. Preliminary validation on 10 subjects showed that the algorithm accurately segmented LIB and AWB. Our method can be helpful in clinical care for fast and economical monitoring of 3D plaque progression and regression during therapy.