Quantifying Plaque Burden of Human Atherosclerotic Plaque Using Cluster Analysis and Active Contours: Toward Improved Analysis

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INTRODUCTION. MR imaging is a non-invasive method for the assessment of atherosclerotic plaque burden (plaque volume and plaque thickness). Despite the continued advances in high spatial resolution MR, accurate automated evaluation of in-vivo images remains problematic. This study investigates the efficacy of an image analysis technique consisting of active contours and cluster analysis to objectively quantify plaque burden in patients with aortic and carotid atherosclerosis.

METHODS. MR imaging was performed on a 1.5-T whole-body system. T2-weighted (T2W) transverse images of the descending thoracic aorta were obtained using a double-inversion recovery (i.e., black-blood) fast spin-echo sequence with ECG-gating during free breathing (1). From the resulting T2W images, the user selects a square region of interest centered on the aorta from the first slice in the study. The program processes this initial region with an active contour (or "snake") (2) to outline the lumen area of the aorta in each slice while at the same time determining the area to be cropped for all slices under consideration (Figure 1). A snake consists of a set of points that define an elastic curve over which energy is defined. The system's overall energy is derived from the energy encapsulated in the snake model itself and the energy supplied from the image under consideration. Minimizing the system's energy function causes the active contour to converge to a stable state and reveal salient image characteristics. Cluster analysis is then performed to segment the image into lumen, plaque and outer wall components. Cluster analysis is an exploratory data-partitioning technique for solving data classification problems. Its aim is to sort data into groups, or clusters, so that the degree of association is strong between members of the same cluster and weak between members of different clusters. Each cluster thus describes, in terms of the data collected, the class to which its members belong. Line-profiles radiating outward from the center of the cluster-analyzed vessel are then extracted in order to delineate the plaque region's external border (Figure 2). In areas where line profiles indicate that plaque thickness deviates dramatically from the average thickness, cluster analysis is iteratively applied on this reduced area at varying scales to produce a well-defined plaque region (Figure 3), which is then extracted (Figure 4). Aortic plaque burden from 24 randomly selected slices from 4 studies was independently assessed by 4 expert MR image readers as well as by the algorithm to produce segmented plaque regions. The adjusted Rand index (ARI) (3) was computed for all possible pairs of segmented images and results subsequently evaluated using a t-test.

RESULTS. As a consequence of the typically high contrast that exists at the lumen wall, snakes easily converged and accurately outlined the lumen. Although the initial cluster analysis of the images produced an adequate segmentation, extracting a contiguous plaque region required additional cluster analysis on selected regions with enhanced contrast. Quantitative comparison of all possible pairs of segmented images using the adjusted Rand index indicated no statistical difference ($p>0.05$) between segmented plaque regions traced by experts (mean ARI=0.588±0.088) and those determined by the proposed algorithm (mean ARI=0.563±0.119). In addition, the automated analysis of all images completed in 4 minutes as compared to the 22±7.52 minutes required by the experts.

CONCLUSIONS. The proposed image analysis was able to quantify plaque burden to within the variability of the experts. This semi-automated approach may facilitate the accurate and rapid study and analysis of atherosclerotic plaque progression and regression in humans non-invasively. With these methods, applicability of atherosclerotic vessel wall imaging in the clinical setting may be now be feasible.

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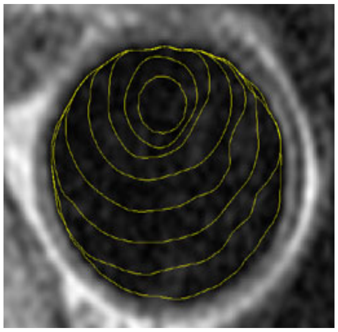

Figure 1.

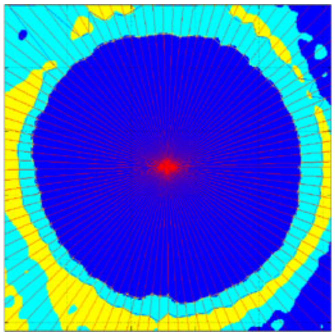

Figure 2.

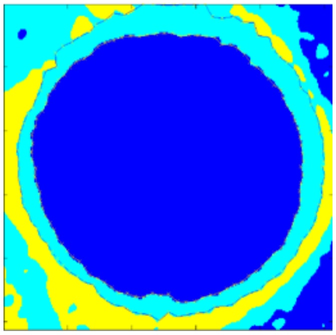

Figure 3.

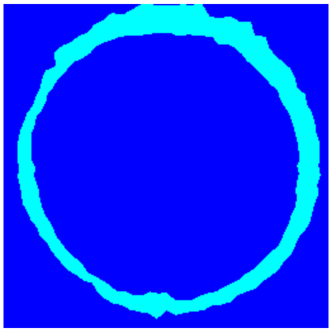

Figure 4.