Hemorrhage Delineation and Blood Suppression Evaluation in Slab-selection Phase-sensitive Inversion-recovery (SPI) Sequence with MRI

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<u>Introduction</u>: Intraplaque hemorrhage (IPH) into the carotid atherosclerotic plaque has shown significant association with clinical symptoms and is believed to be a major factor causing plaque instability and progression according to previous histopathological and prospective studies [1,2]. With the development of magnetic resonance imaging (MRI) in clinical diagnostics, several techniques have been developed to enable and improve the IPH evaluation [3-5]. However, automated hemorrhage detection has been challenging due to either low IPH contrast or poor lumen contrast.

<u>Purpose</u>: In this study, by incorporating the improved IPH and lumen contrasts in Slab-selection Phase-sensitive Inversion-recovery (SPI) MRI sequence [5], we develop a novel and robust image segmentation approach to automatically locate and delineate IPH in MR data. Quantitative IPH and lumen analysis results by this automatic segmentation technique were compared to a human reader, which demonstrated highly consistent performance.

<u>Methods and Materials</u>: **Study protocol**: in this study, five subjects with diagnosed carotid atherosclerotic plaque were recruited after informed consent. These subjects were scanned in vivo in a 3T clinical scanner (Philips Achieva, R2.6.1, Best, the Netherlands) with the SPI protocol. Detailed imaging parameters were: IRTFE sequence, TR/TE 13.2/3.2 ms, TI 400ms, FOV 160x160x32, Voxel size: 0.6x0.6x2mm, reconstructed voxel size: 0.3x0.3x1mm, TFE factor 40, Phase-sensitive reconstruction, imaging time: 2m57s.

Auto IPH Segmentation Method: In SPI images, the IPH region has much higher signal than other pixels in the vessel wall area. Since the absolute MRI signal varies across scan and subject, applying threshold or training based analysis methods is very difficult. Given this consideration, an unsupervised IPH delineation approach is proposed for IPH analysis, which consists of two steps: location and segmentation. i) Location: from the original MR image at each slice, a wall region is outlined with the automatic vessel delineation algorithms developed in previous work [6]. By applying a moving average filter, three separated pixels with the highest MR signal are identified as IPH candidate locations. ii) Segmentation: an enhanced MeanShift based algorithm is used to find the IPH region. The optimal solution is searched by iteratively minimizing the difference between the local mean and the center of distribution which is expressed as: $E[x \mid x \in R_x] - x = \frac{r^2}{4} \frac{\nabla p(x)}{p(x)}$ where R is the distribution cluster with radius r and $p(x)$ is the probability density at location x. Among the segmented regions in the wall area, those containing the three IPH candidate locations are compared and the one with brightest mean signal is selected as the IPH region.

Performance Evaluation: Out of the five subjects, 40 locations with manually identified IPH were blindly analyzed with the proposed automatic approach and by an experienced reader. Figure 1 illustrates the automated processing process. The measured lumen and IPH areas with both methods were compared: i) IPH comparison: IPH regions were identified successfully across all analyzed locations. The IPH area measurements by the proposed algorithm and human readings were highly correlated (r=0.86) as shown in Figure 2. The morphologies of delineated IPH regions with both methods were also very close via visual comparison. ii) Lumen comparison: to evaluate blood suppression of SPI sequence, the areas of lumen regions outlined by automatic algorithm and human readings were also compared. They are also highly related with correlation (r=0.94; Figure 3).
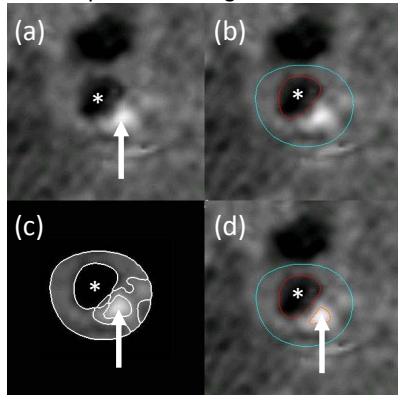

Figure 1 Illustration of IPH delineation.
(a) original image. (b) auto vessel delineation.
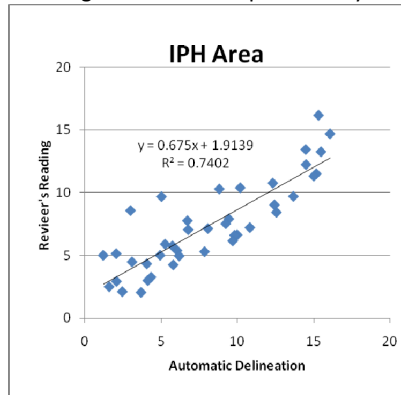(c) wall segmentation map. (d) Final results.
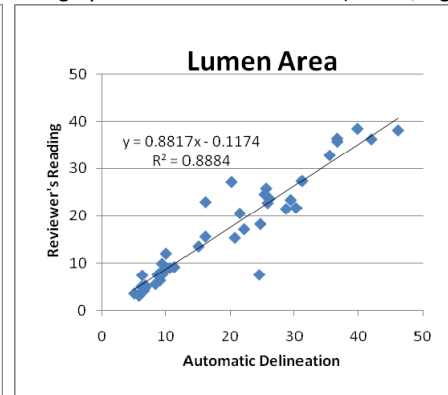*: lumen. Arrow: IPH region.

Figure 2 IPH measurements.

Figure 3 Lumen measurements.

<u>Conclusion</u>: In this work, an innovative Intraplaque hemorrhage delineation method is proposed based on the SPI sequence. With an unsupervised segmentation algorithm as a core, this algorithm can identify the IPH region automatically based on the signal feature in MR images. Its accuracy and reliability have been demonstrated via the high correlation in quantitative comparison with human results. On the other hand, the agreement in lumen analysis results shows the effectiveness of blood suppression in Slab-selection Phase-sensitive Inversion-recovery sequence which is very significant in plaque composition analysis with multiple contrasts weighting MRI.

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