Enhanced Intraplaque Hemorrhage Delineation Method in Slab-selection Phase-sensitive Inversion-recovery (SPI) Sequence with MRI

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Introduction: Atherosclerosis is the number one killer in the world. Previous histopathological and prospective studies [1,2] have shown that intraplaque hemorrhage (IPH) into the carotid atherosclerotic plaque is a major factor causing plaque instability and progression. Thus, IPH is critical to evaluation of carotid atherosclerotic disease. Among techniques proposed for *in vivo* IPH imaging and evaluation [3-5], the Slab-selection Phase-sensitive Inversion-recovery (SPI) MRI sequence is reported to show improved IPH evaluation compared to others due to better IPH contrast[5]. Using this imaging technique, a mean-shift model based automated IPH detection algorithm was developed which shows high correlation with human evaluation on slices with IPH in *in vivo* MR images [6]. However, there are some limitations: 1) when the mean-shift algorithm is applied to SPI slices without IPH, it may be over sensitive and mis-identify IPH regions; 2) for IPH regions with small size or low contrast, mean-shift usually excludes the boundary pixels and under-estimates IPH area measurements. This is caused by the radius of distribution cluster in mean-shift model, which cannot be adjusted rapidly enough during the searching process when encountering MRI images with extensive intensity ranges or that contains IPH with small size and low contrast.

Purpose: 1) develop enhance mean-shift model (eMS) to overcome the existing limitations; 2) evaluate the performance of the eMS algorithm and compare with the previous mean-shift based IPH detect algorithm by using human analysis results as ground truth.

Methods and Materials:

Study protocol: in this study, five subjects with documented carotid atherosclerotic plaque were recruited after informed consent. These subjects were scanned in a 3T clinical scanner (Philips Achieva, R2.6.1, Best, and the Netherlands) with the SPI protocol. For each subject, 32 slices were obtained with the SPI sequence. 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.

Enhanced Mean-shift Delineation Algorithm: With the SPI technique, IPH can usually be accurately identified by mean-shift model on the slices with IPH due to its higher signal than other regions in the vessel wall [6] because IPH pixels are classified as a very distinct cluster in signal space within mean-shift model. However, in slices without IPH, the intensity dynamic range decreases greatly. If the cluster radius during mean-shift searching process cannot change accordingly, vessel wall area is likely over-segmented which can mislead the follow up identification. To overcome this problem, a weighting parameter is introduced in the mean-shift model which dynamically adjusts radius size in each iteration by evaluating the region size and signal features, such as the contrast in each region. With this design, the mean-shift model can intelligently adjust its segmentation scale during the iteration process. The iterative searching process uses the difference between local mean and center of distribution as criteria, 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, which is minimized to find the optimal segmentation. IPH is selected when a region with brightest mean signal is significantly higher than other regions.

Performance Evaluation: 160 images from the five subjects were processed by mean-shift and eMS algorithms respectively. They were also manually analyzed by an experienced reviewer blinded to the two algorithms' results. The reviewer identified 40 slices with IPH. Using human readings as the ground truth, two experiments were conducted to evaluate eMS' performance: 1) *Sensitivity and Specificity comparison:* out of 160 slices, 59 slices were identified with mean-shift algorithm vs. 48 with eMS. Both automatic algorithms could identify IPH across all slices where IPH was found in human readings. Thus, sensitivities for both algorithms are 100%. However, eMS outperforms the mean-shift algorithm with better specificity (93% vs. 84%) and a higher *positive predictive value (ppv)* (0.83 vs. 0.68). 2) *IPH area comparison*: comparing with human IPH area readings, the mean-shift algorithm has a lower correlation than eMS (0.74 vs. 0.89 in R^2 as shown in Figure 2&3). Although morphologies of identified IPH regions in both methods are very close via visual comparison, eMS has a higher accuracy in IPH delineation (shown in Figure 1).

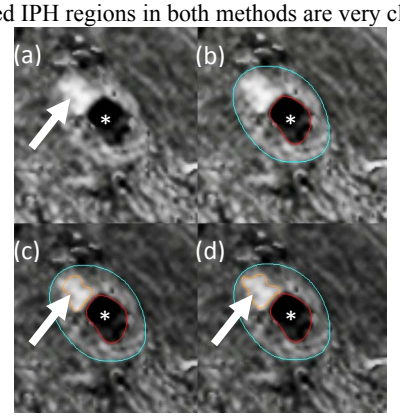

Figure 1 Illustration of IPH delineation. (a)original image. (b) Vessel delineation. (c) Mean-Shift result (d) eMS result. *: lumen. Arrow: IPH region

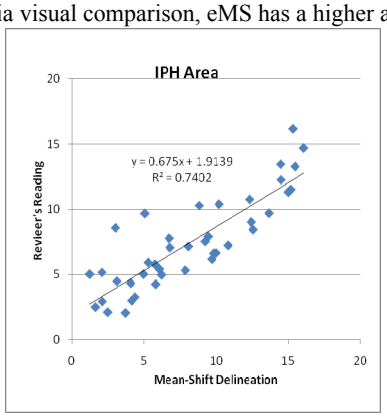

Figure 2 IPH area measurements by manual and mean-shift algorithm delineation.

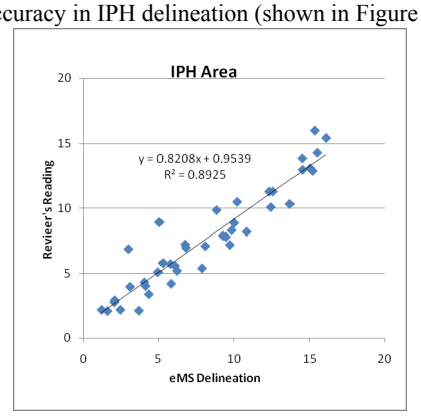

Figure 3 IPH area measurements by manual and eMS algorithm delineation.

Conclusion: In this work, an enhanced intraplaque hemorrhage delineation method is proposed based on the SPI sequence. This new algorithm overcomes the limitations in the previous mean-shift model. Its accuracy and reliability have been demonstrated via the high correlation in quantitative IPH area comparison with human readings and superior performance in specificity and positive predictive value evaluation. This technique potentially can be further developed as a robust and automatic tool for IPH evaluation in clinical carotid atherosclerotic disease.

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