Quantitative Evaluation of Fibrous Cap Status in MRI of Carotid Atherosclerosis

N. Balu[1], W. S. Kerwin[2], M. S. Ferguson[2], C. Yuan[2]

[1]Bioengineering, University of Washington, Seattle, WA, United States, [2]Radiology, University of Washington, Seattle, WA, United States

Introduction

Stroke is a leading cause of morbidity and mortality in the US. A root cause of many strokes is the rupture of the fibrous cap (FC) covering necrotic debris in carotid atherosclerotic plaques. An FC that is thick is considered stable, while thin and ruptured caps are considered prone to new or additional ruptures. Recent studies have shown that 3D-TOF images (bright blood) along with T1 (black blood) MR images can classify fibrous caps into thick, thin and ruptured categories [1] and that the presence of a ruptured cap by MRI is highly associated with a patient's neurological symptoms [2]. In theses studies, 3D-TOF images produced a dark rim around the lumen in the case of a thick cap, while the dark rim was absent for thin or ruptured caps. Ruptured caps were distinguished from thin caps by the presence of a focal abnormality in the lumen boundary on black blood weightings. Problems with these studies are that they only produce categorical evaluations of cap status and they are highly subjective and prone to interobserver variability. To address these shortcomings, this investigation was designed to automate the evaluation of fibrous cap status and to generate a continuous variable describing overall cap integrity. Challenges include the small size of the cap (thin cap < 0.25mm), problems with registration due to patient movement and flow artifacts blurring the lumen/wall interface. After addressing these challenges, the resulting algorithm was validated by comparison with histology.

Materials and Methods

3D time-of-flight (3D-TOF) images (TR-23ms, TE-3.8ms, flip angle-25 degrees, FOV-13cm, Slice thickness-2mm, matrix-256x256, NEX-2) and T1 weighted 2D fast spin echo images (TR-800ms, TE-9.3ms, FOV-16cm, Slice thickness-2mm, matrix-512x512, NEX-2) were obtained on a 1.5T GE Signa scanner, from 7 patients scheduled for endarterectomy. In addition, select images from 5 additional patients previously examined for fibrous cap status were included for algorithm training. Based on these images, the classification algorithm evaluated both the appearance of the dark rim and the presence of focal contour abnormalities. The dark rim evaluation was based on the set of gradient values in the 3D-TOF images computed along a line perpendicular to the lumen boundary. Using the gradient as opposed to intensity avoids problems with image intensity normalization inherent in MR images. Focal contour abnormalities were then detected using the lumen boundary on the T1 image and calculating the ratio of the local curvature to the curvature of the complete contour. The computed gradients and curvature ratios from the two weightings were then registered by aligning the centroids of the convex hulls of the lumen boundaries. For each matched point along the lumen boundary, these parameters formed a feature vector that was compared to templates of the same parameters from the reference set of images previously classified by expert radiologists. A mahalanobis distance classifier was used to perform this classification. To validate the performance of the algorithm, the endarterectomy specimens were removed *enbloc*, sectioned and stained. A pathologist then classified the FC at each point along the lumen boundary according to the same criteria. Pearson's correlation coefficient was used to compare the true FC status (by histology) against the algorithm's classification for each matched slice, where the relative proportions of points classified as thick, thin, and ruptured were used as variables for comparison.

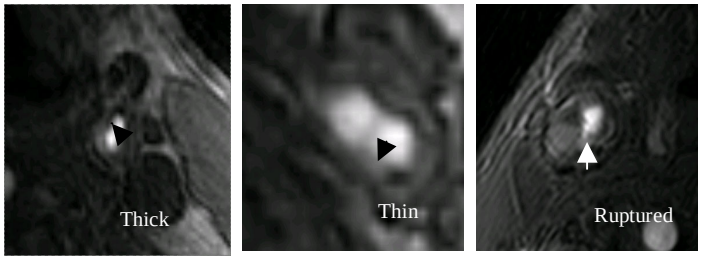
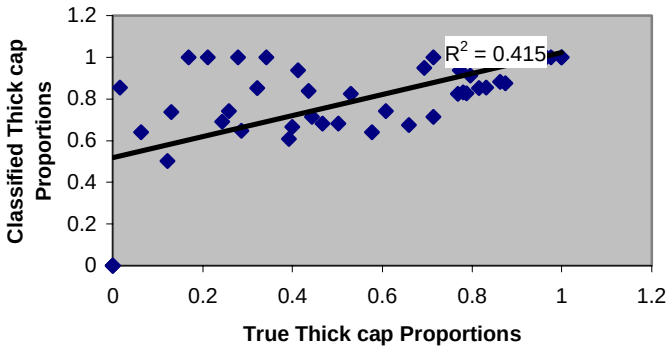
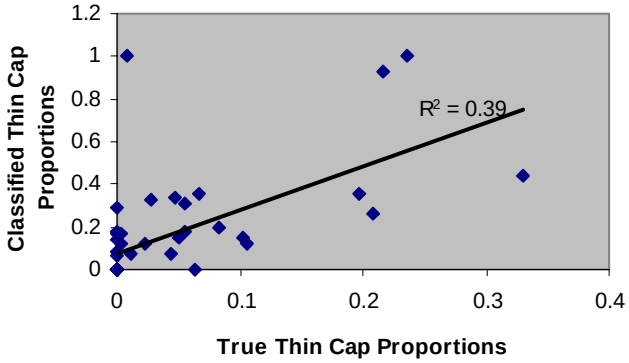


Fig 1: Appearances of thick, thin and ruptured caps on 3D TOF images

Results

In total, 53 matched slices were evaluated from the 7 subjects. There was significant correlation between the classification by the algorithm and corresponding ground truth by histology for thick cap (R=0.64, p<0.0001) and thin cap (R=0.62, p<0.0001). The correlation for ruptured caps was lesser (R=0.34, p=0.014) and might be improved by using other image weightings and radiological markers for rupture.





Conclusions

This study shows the feasibility of an automated, quantitative index for fibrous cap status. Because the algorithm only presumes that the lumen boundary has been identified on 3D-TOF and T1 weighted images, it also shows that stable (thick) and unstable (thin) caps may be identified with minimal user intervention allowing rapid analysis of carotid atherosclerotic MRI for vulnerability criteria. Further improvements in the classification accuracy are possible if additional contrast weightings (e.g. T2 and PDW) are used. For human observers, detection of FC status with four contrast weightings is useful for ruling out sources of artifacts and for identifying other markers of rupture such as hemorrhage [3].

References

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