Segmentation of Carotid Plaque using Multi-Contrast 3D Gradient Echo MR Imaging

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Introduction:

The ability to identify plaque components in atherosclerotic carotid arteries using MRI is well established [1] and is amenable to automatic segmentation with techniques such as Morphology-Enhanced Probabilistic Plaque Segmentation (MEPPS) [2]. Measurements of components, such as necrotic core (NC), calcification (CA) and loose matrix (LM) have enabled researchers to identify plaque features associated with cerebral ischemic outcomes [3] and changes in plaque composition with treatment [4]. To date, these studies have primarily relied on 2D spin echo imaging techniques, but recent advances have led to numerous 3D gradient echo imaging techniques for vessel wall MRI. These 3D techniques, including 3D Magnetization Prepared Rapid Gradient Echo (MP-RAGE) [5] and 3D MSDE Prepared Rapid Gradient Echo (3D-MERGE) [6], offer vastly superior through-plane resolution, signal-to-noise ratio advantages, and scan time efficiency. An interesting possibility that emerges is the identification of plaque components based solely on these 3D sequences, with resulting isotropic, high-resolution maps of plaque components. To evaluate the use of 3D gradient echo imaging techniques to identify plaque components, this investigation sought to compare performance of an automatic segmentation algorithm based on MEPPS using traditional 2D spin echo images versus 3D gradient echo images.

Materials and Methods:

Four subjects with advanced atherosclerosis were imaged on a 3T MR scanner (Philips Achieva) using both an established protocol [1] with 2D T1, T2, and Contrast-Enhanced (CE) T1 turbo spin echo (TSE) images and 3D gradient echo images consisting of time-of-flight (TOF), MP-RAGE and 3D-MERGE. The 2D images were acquired at 2 mm intervals with in-plane resolution of 0.625 mm, whereas the 3D images were acquired with isotropic voxel sizes of 0.7 mm (3D-MERGE) or 0.625×0.625×2 mm (MP-RAGE and TOF).

Custom software (CASCADE [7]) was used to register corresponding locations from all 6 contrast weightings and interactively draw vessel boundaries. Then MEPPS was applied to the 2D T1, T2, CE-T1 and TOF images to identify NC, CA, and LM. MEPPS segments carotid plaque based on a histologically-validated probability model of morphological and MRI signal characteristics. The components were then mapped to the 3D images and used to retrain the probability model of MRI signal characteristics based solely on 3D weightings. After training, we used the new probability model for MEPPS to segment the 3D images at 0.3 mm intervals along the carotid artery. The results were compared to the original 2D segmentation and used to visualize the plaque distribution not only on axial plane, but also on coronal and sagittal planes.

The area of each location was computed for each component. These measurements were compared between 2D and 3D contrast weightings. Bias was assessed by means of a paired t-test, with $P<0.05$ considered a significant level of bias. Agreement was assessed by Pearson's correlation coefficient (R). The comparison of the presence or absence of each location was assessed by Cohen's κ value.

Results:

64 locations (4 subjects, 16 locations for each) were classified and compared between 2D and 3D contrast weightings. The compared component area results are summarized in Table 1. In general, the results show good agreement with correlation coefficients for most components around 0.9 and high κ values for CA and NC. Agreement was moderate for LM with R value 0.63 and κ value 0.32. Fibrous tissue represents remaining unclassified tissue, which was present in all slices and therefore preclude calculation of κ. Significant trends of bias were observed with the areas of CA, NC, and LM. The fibrous tissue was not significantly different between 2D and 3D weightings.

Isotropic data was also generated on the 3D contrast weightings with the voxel size 0.27×0.27×0.30(mm). Segmentation and probability map generation were implemented on the isotropic data. Figure 1 shows the visualization of the probability map on axial, coronal and sagittal planes.

Table 1. Comparison of Classification Results between 2D and 3D Contrast Weightings

Tissue	Average area per slice (mm^2)		*P* value	R	κ
	2D	3D			
CA	0.48	0.17	0.01	0.82	0.78
NC	5.65	8.54	<0.001	0.91	0.91
LM	2.43	0.48	<0.001	0.63	0.32
Fibrous	26.97	26.90	0.88	0.91	

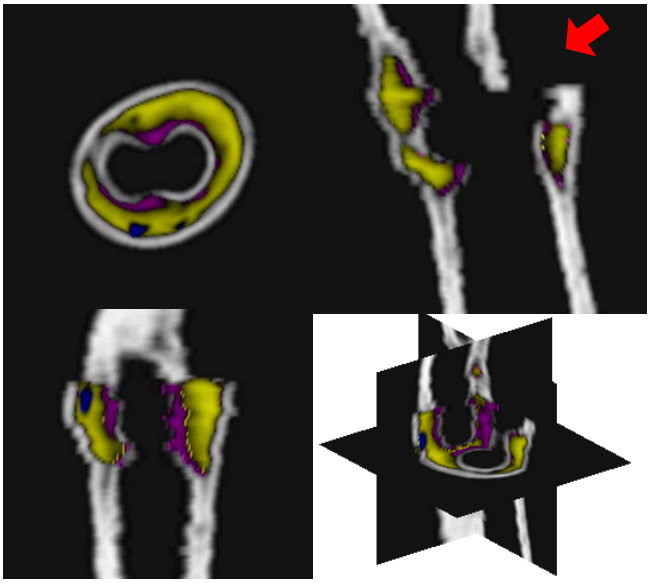

Figure 1. Visualization of the automatic classification results. Fibrous is white, loose matrix is purple, calcification is blue and necrotic core is yellow. Boundaries of ECA were not outlined and represent the discontinuity in the vessel wall (arrow).

Discussion and Conclusions:

The results of this work show in principle that a protocol based on 3D gradient echo contrast weightings provides sufficient information to quantitatively characterize CA, NC, and LM in carotid atherosclerotic plaque. Although discrepancies in absolute size were noted, strong correlations and high κ values suggest that with proper training and adjustment, robust automated segmentation based on 3D gradient echo images is possible. Of course, this result must be replicated with a larger sample size, which may, in fact, improve the result as the distribution of components is more accurately characterized. LM may, however, remain challenging as it is best depicted on T2-weighted and CE images. Finally, this study did not seek to separate NC into lipid and hemorrhage (IPH) components, but given the sensitivity of MP-RAGE to IPH [5], this should be possible.

Overall, the advantage of this approach is especially well represented by the 3D visualization results. The isotropic segmentation results permit visualization of plaque structure in arbitrarily reformatted cuts.

References

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