Characterization of Carotid Atherosclerotic Plaque Compositions by Single Magnetic Resonance Imaging Sequence: A Comparison Study with Multicontrast Plaque Imaging at 3T

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Introduction: Carotid multicontrast (Time of flight [TOF], T1-, T2-, and proton density-weighted [PDw]), high resolution, vessel wall magnetic resonance (MR) imaging has been widely used for characterizing atherosclerotic vulnerable plaques [1,2] and monitoring the effects of statin therapy in clinical trials [3,4]. However, the long scan times for acquiring all the contrast weightings using the suggested protocol limit direct clinical application of this imaging technique. Recent 3D imaging techniques can provide isotropic high resolution imaging with large coverage and short scan times. Use of '3D **M**otion-sensitive Driven **E**quilibrium Prepared **R**apid **G**radient **E**cho (3D-MERGE)' for vessel wall imaging [5] can potentially be used for fast assessment of plaque morphology [5] and plaque composition. While plaque morphology assessment with 3D-MERGE has been compared to single contrast weighting (PDw) [5], its performance compared to multicontrast MRI for both morphology and compositional assessment has not been studied.

Purpose: This study sought to evaluate the ability of 3D MERGE in characterizing plaque morphology and composition compared to a previously validated multicontrast MR imaging protocol.

Methods: Thirteen patients (mean age 62 years, 9 males) with recent transient ischemic attack or stroke underwent carotid MR imaging on a 3.0 T whole-body scanner (Achieva, Philips Medical System, Best, Netherlands) using a carotid dedicated 8-channel, phased array coil. Both multicontrast MR imaging (3D TOF, T1w, and T2w) and 3D MERGE were performed covering bilateral arteries for all the patients in the same imaging session. ***MR imaging parameters:*** 1) multicontrast MRI: 3D TOF: TR/TE 20/4ms, flip angle 20°; T1w: quadruple inversion-recovery (QIR) [6], black-blood, 2D TSE, TR/TE 800/10ms; T2w: Multi-slice Double IR (MDIR), TR/TE 4800/50ms. All images were acquired using field of view (FOV) 14cm x 14 cm^2, acquisition matrix 256x256, slice thickness 2 mm, and in-plane resolution 0.55mmx0.55mm; 2) 3D MERGE: TR/TE 10/4.8 ms, FOV 25 x 16 x 7 cm^3, isotropic resolution 0.7 x 0.7 x 0.7 mm^3, effective foot-head coverage > 80 cm, and scan time 2 minutes. ***Image interpretation:*** The coronally acquired 3D MERGE MR images were reconstructed in the axial plane with 1 mm slice thickness such that the reformatted slices matched multi-contrast MRI. Two trained reviewers interpreted (by consensus) bilateral carotid multicontrast MR images blinded to 3D MERGE MR images. After an interval of three months, the same two reviewers explained the 3D MERGE MR images blinded to multicontrast MR images. All image interpretation was conducted using custom-designed software (CASCADE [7], Seattle, WA, USA). The lumen area (LA), wall area (WA), total vessel area (TVA) and mean wall thickness (MWT) were measured at each axial location. In addition, the presence or absence of plaque components, such as calcification, lipid-rich necrotic core (LRNC), and intraplaque hemorrhage (IPH) was identified using previously published criteria for multicontrast images [8] and 3D-MERGE [9] independent of each other. The area of plaque components was also measured. ***Data analysis:*** The volumes of lumen, wall, total vessel, and plaque compositions were determined for each artery. The intraclass correlation coefficients (ICCs) and 95% confidence intervals (CIs) were calculated to assess the agreement between multi-contrast protocol and 3D MERGE for quantitative assessment of plaque morphology and compositions. The Cohen's Kappa (κ) was analyzed to evaluate the agreement between multi-contrast protocol and 3D MERGE for identification of plaque compositions. Statistical significance was defined as a value of $P<0.05$.

Table 1. Intraclass Correlation Coefficients for plaque morphology and composition measurements.

	N (arteries)	Multi-contrast vs 3D MERGE		*P*
		ICC	95% CI	
Lumen volume	26	0.992	0.982-0.996	< 0.001
Wall volume	26	0.806	0.567-0.913	< 0.001
Total vessel volume	26	0.992	0.982-0.996	< 0.001
Mean wall thickness	26	0.873	0.717-0.943	< 0.001
Calcification	8	0.545	-1.271-0.909	0.160
Lipid-rich necrotic core	10	0.753	0.005-0.939	0.025

Results: There was good agreement between multicontrast MRI and 3D MERGE in measuring carotid plaque morphology (Table 1). For identification of presence of carotid plaque compositions by multicontrast protocol and 3D MERGE, the Kappa value was 0.615 (P = 0.001) for calcification, 0.480 (P = 0.008) for LRNC. No patients had detectable IPH by either multicontrast protocol or 3D MERGE. IPH was therefore excluded from further analysis. For quantification of carotid LRNC, a moderate agreement was observed between multicontrast protocol and 3D MERGE sequence (Table 1, Fig. 1). However, there was poor agreement in measuring the size of carotid calcifications between these two imaging approaches (P = 0.160) with 3D-MERGE detecting larger calcification volume compared to multicontrast protocol (33.6 $\pm$27.6 mm^3 vs. 25.8 $\pm$12.8 mm^3).

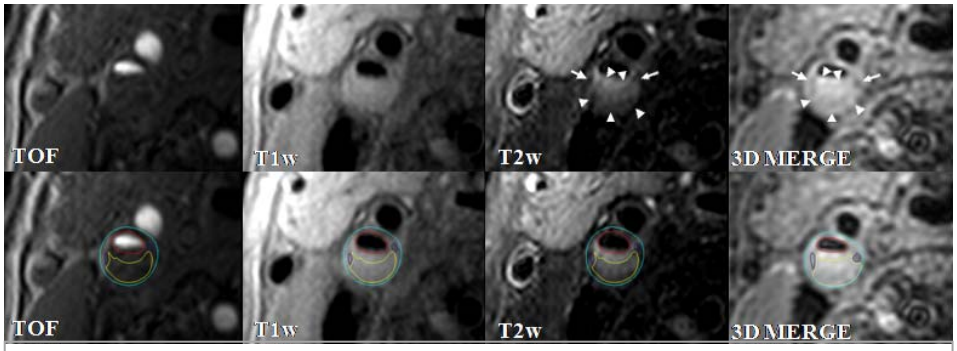

Fig. 1: Pre- (upper row) and post-outlined (lower row) MR images showed a lipid-rich plaque in right internal carotid artery. Large LRNC (arrow head, yellow lines) appears slight hypointense on T2w image in multicontrast protocol and 3D MERGE image. Calcification (arrow, blue lines) appears hypointense on both multicontrast and 3D MERGE images. There is a good agreement between multicontrast and 3D MERGE for assessing plaque compositions.

Discussion and Conclusions: We found a good agreement between 3D MERGE and multicontrast protocol in measuring the plaque morphology in carotid artery. This suggests that 3D-MERGE exhibits sufficient lumen and vessel wall contrast which is necessary for delineating the lumen and outer wall boundaries. Since 3D MERGE is both T1 and T2 weighted [9], it is a good candidate sequence for plaque component screening. The findings of this study demonstrate that, by using 3D MERGE alone, it is feasible to determine the presence of calcification or LRNC. Detection of IPH could not be assessed due to smaller sample size with low prevalence. However, measurement of calcification size differs on 3D-MERGE. This may be due to either improved sensitivity of 3D-MERGE for detection of calcification [9] or increased susceptibility effect from gradient echo acquisition compared to the spin echo based multicontrast protocol. Further studies are warranted for detection and measurement of calcification and IPH. Due to its isotropic acquisition, larger coverage, and short scan time, 3D-MERGE is an ideal screening tool for assessment of plaque burden, detection of lipid rich plaque and measurement of lipid core. If other complex plaque features such as calcification and IPH are suspected, the regular multicontrast MR protocol can be performed on the region of interest. Alternatively, other fast 3D sequences, such as 3D TOF (detection of calcification, IPH, and fibrous cap rupture [10,11]) and 3D MPRAGE (identification of IPH) [12], can be combined with 3D MERGE for comprehensive characterization of atherosclerotic plaques with large coverage.

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