Carotid plaque burden measurement using ultrafast 3D black-blood MRI

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Introduction: Black-blood (BB) MRI can quantitatively measure carotid plaque burden and thereby help assess the risk of stroke. Current plaque imaging protocols using 2D BB sequences have been validated to provide precise plaque burden measurements thru measures such as wall area and wall thickness. However they have low resolution in the slice select direction and provide limited slice coverage. Alternative 3D sequences are limited by prohibitively long scan times, inadequate flow suppression, and non-isotropic voxel size due to SNR restrictions. To address these challenges an ultrafast isotropic black-blood carotid MRI sequence was developed: 3D motion-sensitized driven equilibrium (MSDE) prepared rapid gradient echo (3D-MERGE) which utilizes the recently developed MSDE black blood preparation [1,2]. 3D-MERGE imaging can potentially provide plaque burden assessment along a large segment of the artery (fig 1) under a 2 minute scan time.

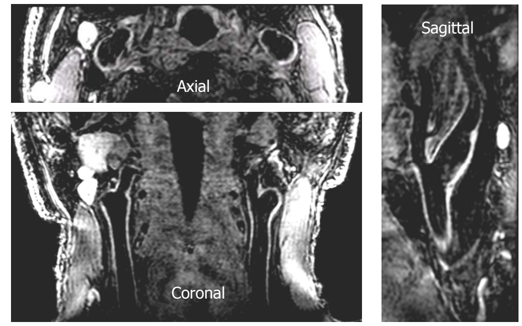

Fig 1 Reformats of isotropic 3D-MERGE in all three planes showing good blood suppression and wall definition

Aims: 1) To compare the new 3D-MERGE sequence to Turbo Spin Echo (TSE) based 2D PDw MSDE for plaque burden measurement. 2) To assess the blood suppression efficiency of 3D-MERGE.

Materials and Methods: Imaging: 9 patients with 16-79% carotid stenosis by duplex ultrasound were scanned according to IRB guidelines on a Philips Achieva 3T scanner with bilateral carotid coils. 3D-MERGE was implemented with MSDE preparation and spoiled segmented FLASH (T1-TFE) readout with centric phase encoding. Sequence parameters (Table 1) were adjusted to obtain isotropic resolution of $0.7mm^3$ (zero-interpolated to $0.35mm^3$) with a scan time of 2 min. Images were acquired in the coronal plane to image the entire carotid artery covered by the coil. 2D PDw MSDE was obtained in the axial plane. **Image analysis:** 3D-MERGE images were reformatted in the axial plane with a 2mm slice thickness such that slices were registered to PDw (fig 2). Bilateral carotids (18 arteries) were reviewed independently on 3D-MERGE and PDw. Lumen and outerwall boundaries were drawn on all slices with the carotid bifurcation serving to match the images. SNR was calculated as SI/σ where SI is the signal intensity and σ the standard deviation of noise. CNR and CNR efficiency [1] were defined as follows:

Table 1: Imaging Parameters

	3D MERGE	PDw MSDE
Mode	3D	2D
Acquisition plane	Coronal	Axial
Black-blood Prep	MSDE	MSDE
Resolution, mm^2	0.7	0.63
FOV, mm^2	250×160	140x140
Slice thickness , mm	0.7	2
# of slices	100	16
TR/TE, ms	10/4.8	4000/10
Flip angle, °	6	90
Turbo factor	90	12
BW, Hz/pixel	134.3	201.1
NSA	1	1
Scan time, min:s	2:03	2:32

$$CNR = SNR_{wall} - SNR_{lumen} \qquad CNR_{eff} = \frac{CNR}{V_{voxel}\sqrt{T_{slice}}}$$

V_{voxel}: Voxel volume, T_{slice}: Slice acq

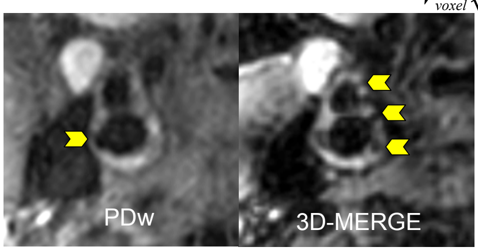

Fig 2 Matched slices of highly calcified lesion: Large calcification is visible on both sequences but smaller calcifications are better visualized on 3D MERGE.

Lumen, wall and CNR measures were calculated for all slices and averaged per artery. Artery level measurements of lumen area, wall area, CNR and CNR efficiency were compared between the two sequences. **Statistical analysis:** Plaque burden measurements (Table 2), CNR and CNReff were compared using paired student t-test. Plaque burden measurements were also compared using intraclass-correlation coefficients (ICC) and Bland-Altman plots.

Table 2: Comparison of plaque burden measurements

	3D MERGE	PDw MSDE	T-test p	ICC
Lumen Area (mm^2)	35.9 ± 8.7	37.4 ± 9.3	0.16	0.983
Wall Area (mm^2)	29.3 ± 4.7	29.0 ± 3.8	0.12	0.885
Mean WT (mm)	1.18 ± 0.14	1.15 ± 0.14	0.04	0.795
Max WT (mm)	1.7 ± 0.3	1.6 ± 0.3	0.09	0.826

p-values for all ICC <0.001

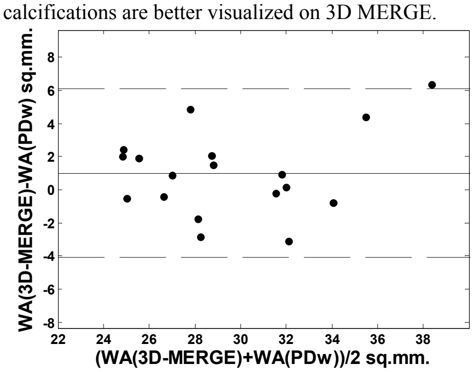

Fig 3 Bland-Altman plot of Wall Area Measurements

Results: Both sequences visualized wall morphology clearly (fig 2) but small plaque components such as calcification were better visible on 3D-MERGE. CNR was lower on 3D-MERGE compared to PDw (15.9 ± 7.2 vs 28.1 ± 17.1; p<0.001). However, CNReff of 3D MERGE was higher (115.1±51.6 vs 89.7± 54.4; p<0.009). There was no difference in artery level lumen and wall area measurements (Table 2, fig 3). There was good agreement shown by ICC for artery level area measurements (table 2). Good ICC was also observed for slice level lumen area measurements (ICC: 0.955; p<0.001) and wall area measurements (ICC: 0.920; p<0.001). There was no difference in artery level lumen SNR between the two sequences (9.3±2.7 vs 9.4±5.0; p=0.96)

Discussion: 3D-MERGE provides comparable blood-suppression as evidenced by comparable lumen SNR to 2D PDw MSDE. This suggests that the CNR of 3D-MERGE can be improved by increasing NEX to 2. Vessel wall measurements on 3D-MERGE were also comparable to validated methods of plaque burden measurement. Accuracy of thickness measurement [3] and reproducibility [4] are expected to be improved by use of 3D-MERGE over 2D sequences.

Conclusion: 3D-MERGE sequence provides an ultrafast method for plaque morphology measurement with extended coverage compared to existing 2D-methods. It offers the benefit of better resolution along the slice select direction for plaque measurement and allows interactive reformatting in arbitrary planes due to its isotropic resolution. Thus 3D-MERGE promises to be a better tool for fast plaque burden measurement and is well suited for clinical studies with plaque burden as the primary endpoint.

References: [1] Koktzoglou, Radiology 2007; 243:220-8; [2] Wang, MRM 2007; 58:973-81, [3] Antiga, MRM, 2009; 60:1020-8, [4] Balu, MRM, 2007, 57:592-9.