Efficient Flow Suppressed MRI Improves Reproducibility of Carotid Atherosclerosis Plaque Burden Measurements

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Background: Black-blood (BB) MR vessel wall imaging has been demonstrated to be a useful tool for in vivo atherosclerotic disease assessment [1-4]. One challenge for BB MR vessel wall imaging is plaque-mimicking flow artifacts due to insufficient flow suppression. Within the unique geometry of the carotid artery, complicated flow patterns such as recirculatory, slow or stagnant flow frequently present at the carotid flow divider and may produce plaque-mimicking flow artifacts. Previous studies found that a turbo spin-echo (TSE) based motion-sensitized driven-equilibrium (MSDE) sequence, using as an alternative BB carotid MRI imaging scheme, provides more efficient residual flow signal suppression than standard multislice double inversion recovery (mDIR) [5]. However, whether this improved flow-suppression can improve the reproducibility in atherosclerotic burden measurement is unknown.
Purpose: We hypothesized that improved flow-suppression can substantially reduce the variability in atherosclerotic burden measurements. To test this hypothesis, we compared the inter-scan reproducibility obtained using MSDE and mDIR techniques in a clinically relevant population.
Methods: Eighteen subjects with carotid artery stenosis identified by duplex ultrasound (11 with 16-49% stenosis; 7 with 50-79% stenosis) underwent two carotid MRI examinations on a 3T scanner with a 4-channel phased array coil. High-resolution intermediate-weighted turbo-spin-echo sequences with two different flow suppression techniques (mDIR and MSDE) were obtained separately. The additional parameters for the MSDE preparative sequence (5) were motion sensitizing gradient strength 15mT/m, duration 4.5ms, m1 = 715mTms^2/m. The additional parameters for mDIR preparative sequence [6] were TI=230 ms, 8 slices per TR. The acquisition sequence for both was the same: TR/TE = 4000/8.5ms, ETL = 12, FOV = 140 x 140, matrix = 256 x 256. 0.55mm in-plane resolution, 2mm slice thickness, inter-slice spacing = 0 mm, 16 slices, 3min scan time. For each subject, bilateral arteries were reviewed. One radiologist, blinded to time point and flow suppression technique, graded image quality (ImQ) for each axial image of each artery (ImQ; 4-point scale: 1=poor, 4=excellent) using a method described previously [7]. For images with ImQ ≥ 2, the radiologist outlined the lumen and outer wall boundaries using a custom-designed plaque analysis software [8] (CASCADE, Vascular Imaging Laboratory, University of Washington, Seattle, WA). Measurements for lumen area (LA), total vessel area (TVA), and wall area (WA = TVA - LA) were conducted for each axial location by CASCADE. Reproducibility was expressed as the intra-class correlation coefficient (ICC), standard deviations (SD) and inter-scan coefficient of variation (CV) (= 100%*inter-scan SD/overall mean). A linear mixed model for the plaque measurements by location was used to compare the reproducibility at the two flow-suppression techniques.
Results: Bilateral carotid arteries (n=36) from 18 asymptomatic subjects were imaged twice within one month; the average interval of repeated scans was 12 days (± 8.9). Of the 576 locations available for review, after image registration, 486 matched locations (84.4%) were judged to have adequate image quality (ImQ ≥ 2) on both time points and both techniques for further review. Three-hundred and ninety matched locations were included in the final analysis after an additional 96 locations from 6 contralateral arteries were excluded due to insufficient coverage of carotid bifurcation. Compared to mDIR, the MSDE technique had a smaller inter-scan SD for lumen area (LA) measurement (3.6 vs. 5.2 mm^2, p = 0.02) and wall area (WA) (4.5 vs. 6.4 mm^2, p = 0.02), with a similar trend for total vessel area (TVA) (4.4 vs. 4.9 mm^2, p = 0.07) (Table 1). ICC values range from 0.90 to 0.99 for traditional mDIR flow suppression, and from 0.93 to 0.99 for improved MSDE flow suppression (Table 2). Bland-Altman plots for inter-scan measurements (Fig 1) demonstrate random error scattering patterns with no significant bias and no significant correlation between bias and mean for both flow suppression techniques.

Table 1. Comparison of Inter-scan Reproducibility of mDIR and MSDE techniques in each segment of carotid artery

	Common carotid: SD (CV)			**Bulb: SD (CV)**			**Internal Carotid: SD (CV)**		
	mDIR	**MSDE**	**P value**	**mDIR**	**MSDE**	**P value**	**mDIR**	**MSDE**	**P value**
Lumen Area	4.4 (10.6%)	3.5 (8.4%)	0.6	7.0 (16.1%)	4.5 (10.4%)	*0.046*	3.5 (15.1%)	2.3 (9.8%)	*0.04*
Wall Area	5.6 (16.5%)	4.2 (12.5%)	0.2	7.9 (18.5%)	5.4 (12.5%)	0.11	5.2 (19.5%)	3.8 (14.2%)	*0.003*
Total vessel Area	4.1 (5.4%)	4.3 (5.8%)	0.9	6.0 (7.0%)	5.2 (6.0%)	*0.03*	4.1 (8.2%)	3.5 (7.0%)	0.2

Common carotid: >4 mm proximal to the bifurcation; Carotid bulb: 0 mm to 2 mm proximal and distal to the bifurcation; Internal carotid: >2 mm distal to the bifurcation

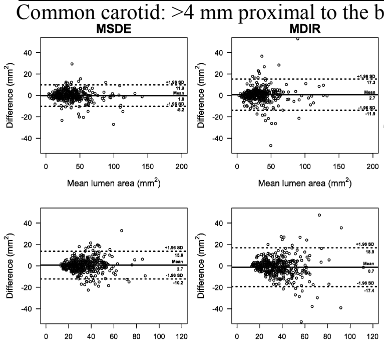

Fig 2. Bland-Altman plots for lumen area (the top panels) and wall area (bottom panels) measurements in both flow-suppression techniques.

Table 2. ICC of Plaque burden on mDIR and MSDE techniques

	mDIR			**MSDE**		
	Scan	**Rescan**	**ICC**	**Scan**	**Rescan**	**ICC**
LA	34.71	33.94	0.93	36.93	37.05	0.97
WA	35.15	36.49	0.74	34.34	33.42	0.88
TVA	69.70	70.36	0.97	70.98	70.45	0.98

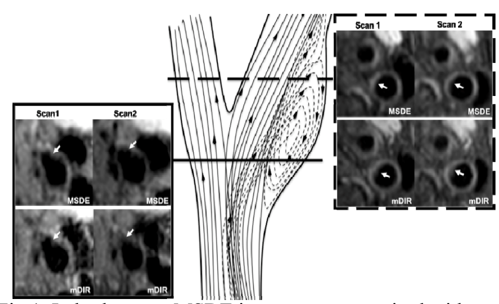

Fig 1. In both cases, MSDE images were acquired with sufficient blood suppression and yield similar lumen/wall boundary contours. MDIR images, however, presented different lumen/wall contours because of different flow artifact patterns at different time points (arrow).

Discussion and Conclusion: The results demonstrate that the reproducibility for both lumen and wall area measurements in the vessel wall imaging can be significantly improved by utilizing a more efficient flow suppression technique. This relationship between flow suppression efficiency and the reproducibility of plaque measurements is important as more reliable area measurements will be useful in clinical diagnosis and in serial MRI studies to monitor lesion progression and regression.

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