Multiplatform reproducibility of 3D carotid vessel wall MRI

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Introduction: Carotid atherosclerosis is a leading cause of morbidity and mortality due to stroke. Although most frequent at the carotid bifurcation, atherosclerosis can extend both proximally and distally. Thus large coverage multi-contrast MRI using 3D sequences has been successfully used by several groups for plaque burden assessment [1-3] as well as identification of plaque components [4, 5]. However their application in large scale clinical trials that typically recruit patients across multiple centers is limited by lack of standardized protocols across scanner platforms. In addition the reproducibility of measurement using 3D sequences has not been determined.

Aims: 1) To implement multi-contrast 3D vessel wall MRI across three major scanner platforms (3T GE, Philips and Siemens) 2) To assess the reproducibility of plaque burden and plaque component assessment in a multicenter setting using the standardized protocol.

Materials and Methods: ***Image Acquisition:*** Three imaging sites participated in the study. A 3D protocol (table 1) was implemented on a GE 3T Signa HDx, Philips 3T Achieva and Siemens 3T Trio with closely matched imaging parameters. Two sequences were used: SNAP [4] and 3D-MERGE [5]. 3D-MERGE was repeated 5 min after injection of Gadolinium contrast (Omniscan or Multihance, 0.05mmol/kg at 1cc/sec). Dedicated phased array carotid coils were used on all platforms (Custom 4 channel array on GE, custom 8 channel phased array on Philips and custom 16 channel phased array on Siemens). ***Subjects:*** Eight subjects with 50-79% stenosis were recruited. They were scanned twice within a 2 week interval.

Image reconstruction: Phase corrected real images were reconstructed for SNAP MRI [4]. All scans were reformatted to 2mm axial slices to facilitate image review.

Image Analysis: A trained reviewer outlined plaque morphology and identified plaque composition using custom plaque analysis software on bilateral carotid arteries (N=16). Both scan time points were reviewed independent of each other. Lumen and outerwall contours were drawn and presence/absence was noted for each of intraplaque hemorrhage (IPH), calcification (CA), lipid-rich necrotic core (LRNC) and ulcer. ***Statistics:*** Quantitative measurements were summarized as mean ± standard deviation (SD) and qualitative measurements were summarized as count (percentage). Artery-level reproducibility of quantitative measurements was evaluated by testing for bias between scans, estimating the within-artery SD, the within-artery coefficient of variance (CV) and intraclass correlation coefficient (ICC). The reproducibility of qualitative measurements was evaluated using Cohen's κ. To account for correlation between arteries of the same subject, linear mixed models (LMMs) were used to estimate parameters and perform hypothesis tests for the quantitative measurements. Data analyses were conducted using R 2.14.1 (R Foundation for Statistical Computing, Vienna, Austria). Statistical significance was defined as $P<0.05$ (two-tailed).

Table 1. Imaging protocol

	SNAP	3D-MERGE
Contrast	No	No/Yes
Sequence[a]	IR-TFE/SPGR	T1-TFE
Image mode	3D	3D
Scan plane	Axial/Coronal	Coronal
TR, msec	13	Min
TE, msec	Min	Min
Flip angle	11°	6°
FOV, cm	16x16	16x16
Resolution, mm²	0.8x0.8	0.8x0.8
Thk, mm	0.8	0.8
# slices	50	50
Blood suppression[b]	Phase-sensitive Recon.	iMSDE
Fat suppression	Yes (Water Excitation)	Yes

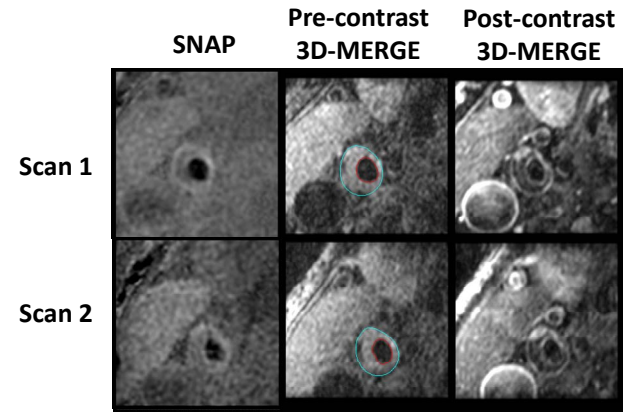

Figure 1. Representative images from one subject showing lumen contour (red) and outerwall contour (blue)

Results: Distribution of subjects across scanner platforms was 4 Siemens, 3 Philips and 1 GE. Representative images from one subject are shown in fig 1. Reproducibility of plaque component assessment is shown in table 2. Reproducibility of morphological measurements is given in table 3. ICC was good to excellent for all morphological measurements. There was perfect agreement for detection of CA and IPH and good agreement for LRNC..

Table 2. Reproducibility of qualitative plaque features (N=16 arteries)

	N (%)		
	Scan 1	Scan 2	Cohen's κ
Presence of LRNC	11 (69)	13 (81)	0.67
Presence of CA	14 (88)	14 (88)	*1.00
Presence of IPH	4 (25)	4 (25)	*1.00
Presence of Ulcer	4 (25)	2 (12)	0.60

*Perfect agreement was observed.

Discussion and Conclusions: Quantitative morphological and qualitative compositional assessment of carotid plaque using a 3D multicontrast MRI protocol showed good to excellent reproducibility. CV of plaque burden measures such as percent wall volume was comparable (3.4% vs 4.2%) to 2D multicontrast MRI [3]. Our reproducibility study suggests that serial 3D MRI studies of plaque burden progression/regression can be conducted on a multi-site, multiple platform basis. Further studies are needed to validate quantitation of plaque composition.

References: [1] Bornstedt, MRM 2008;59:1207-1211, [2] Fan, JMRI 2010;31:645-654, [3] Hayashi, Int JCI 2010 26:309-21, [4] Wang MRM 2013; 69(2):337-45, [5] Balu, MRM 2011;65:627-37. [3] Li, MRM 2009, 31(1): 168-176.

Table 3. Reproducibility of quantitative measurements of vessel morphology (N=16 arteries)

	Mean ± SD		p	SD	CV	
	Scan 1	Scan 2	(bias)	(within)	(within)	ICC
Mean wall thickness, mm	1.5 ± 0.5	1.5 ± 0.4	0.28	0.09	5.7	0.96
Max wall thickness, mm	4.4 ± 1.5	4.1 ± 1.4	0.31	0.57	14	0.84
Mean wall area, mm²	37 ± 13	36 ± 12	0.41	2.2	5.9	0.97
Mean lumen area, mm²	31 ± 8.7	32 ± 8.1	0.27	1.3	4.0	0.98
Mean total vessel area, mm²	69 ± 16	68 ± 15	0.85	2.1	3.1	0.98
Mean percent wall area, %	54 ± 8.4	53 ± 7.3	0.23	1.9	3.5	0.94
Wall volume, mm³	1520 ± 459	1494 ± 422	0.41	87	5.7	0.96
Lumen volume, mm³	1319 ± 420	1344 ± 415	0.17	50	3.8	0.99
Total vessel volume, mm³	2839 ± 609	2837 ± 619	0.96	86	3.0	0.98
Percent wall volume, %	53 ± 9.7	53 ± 8.6	0.24	1.8	3.4	0.96

CV (within)=within-artery coefficient of variation; SD=standard deviation; SD (within)=within-artery SD.