Comparison between 2D and 3D black blood imaging of the clinically significant carotid atherosclerotic plaque

N. Balu[1], B. Chu[2], T. Hatsukami[3], C. Yuan[2], and V. L. Yarnykh[2]

[1]Bioengineering, University of Washington, Seattle, WA, United States, [2]Radiology, University of Washington, Seattle, WA, United States, [3]Surgery, University of Washington, Seattle, WA, United States

Introduction: Plaque morphometry by serial high-resolution MR imaging of carotid artery wall is used in monitoring of atherosclerotic progression and to evaluate effects of therapeutic intervention. Additional information on plaque composition is also being used to predict symptomatic status. Such studies are currently based on single or multi-slice 2D image acquisition and are limited by low spatial resolution along the slice select direction. 3D imaging offers advantages in resolution and signal to noise ratio (SNR) and has been described for carotid arteries [1-3]. Substituting 3D for 2D protocols used in clinical trials requires equivalence of morphometric measurements to be demonstrated at a minimum. To date direct comparison between 2D and 3D imaging for quantitative carotid morphometry in clinically significant atherosclerosis had not been done.

Purpose

To compare 2D and 3D protocols optimized for carotid plaque imaging and to evaluate the effect of increased resolution along the slice select direction on the precision of clinically relevant carotid morphometric measurements.

Methods

17 patients with 50-79% stenosis were scanned with 2D and 3D DIR FSE black blood imaging on a 1.5 GE Signa scanner with bilateral carotid coils with four elements as part of an IRB approved study. Previously optimized 2D [4] and 3D [1] protocols were used. Detailed scan parameters are given in table 1. Lumen and outer wall boundaries were outlined using a semi-automated method [5] for 2D and 3D independently with a 2-week interval between outlines. The carotid bifurcation was identified to match between 2D and 3D images. Reformatted 3D slices (3Dr) that matched 2D slices were obtained by pixel-by-pixel averaging of appropriate images. 3Dr was used to assess measurement variability with its improvement in SNR. Lumen and outer wall boundaries were also drawn on 3Dr. The following morphological measurements were calculated: lumen volume (LV), Wall volume (WV), mean wall thickness (MWT), max wall thickness (maxWT) and minimum lumen area (minLA). Lumen signal-to-noise ratio (SNR_l), wall SNR (SNR_w) and contrast-to-noise ratio (CNR) were also obtained using the outlines. Four regions of interest at the corners of the image free of signal and artifacts were used to estimate standard deviation of noise for calculating SNR. Morphometric measurements from 2D, 3D and 3Dr were compared using a paired t-test. Bias was examined using Bland-Altman plots [6]. Finally, an expert reader compared 2D and 3D side-by-side to assess their ability to resolve small plaque components such as calcification.

Results

There was no significant difference in LV,WV, MWT, maxWT and minLA (table 2) between 2D and 3D. The slightly increased flow artifacts in 3D did not impede visualization of the lumen boundary. There was also no significant difference of these measurements between 2D and 3Dr (table 3). No significant bias was observed on the Bland-Altman plots (figure 1 – shows WV, the most used measure). SNR_l and SNR_w were also comparable between 2D and 3D. Small plaque components such as calcium were better observed in 3D compared to 2D (Figure 2). This shows that slice resolution is critical for detection of small plaque components and 3D imaging is superior in this regard.

Discussion and Conclusions

Major morphological parameters are fully compatible between 2D and 3D methods. A 3D protocol can substitute a 2D protocol without affecting the precision of morphometric measurements with better characterization of small plaque components. If SNR improvement is needed, one can use reformatted 3D images. Moving to a 3D protocol with isotropic resolution while maintaining scan time would further improve measurement precision through improved registration between time points by reformatting. Since the magnitude of changes in plaque burden is small compared to measurement variability, clinical trials would benefit by improved sensitivity and lesser subject recruitment.

Table 1: Scan Parameters

Parameter	2D DIR FSE	3D DIR FSE
TR (ms)	800	600
TE (ms)	11	27
TI (ms)	330	260
FOV (mm)	16 x 12	16 x 12
NEX	2	1
Number of slices	10	40
Echo train	8	8
Matrix	256x256	256x256
Scan time (min)	6.5	6
Slice thickness (mm)	2	1*
Slab thickness (mm)	NA	20

*(interpolated to 0.5)

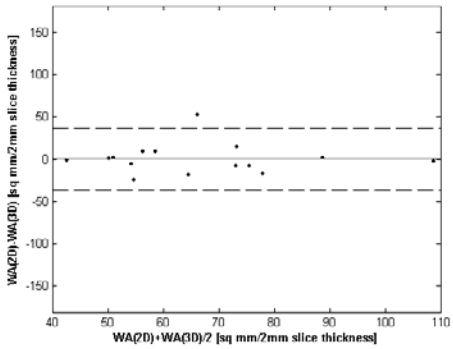

Figure 1: Bland-Altman plot showing agreement for wall volume measurements between 2D/3D

Table 2: Comparison of morphological measurements

Measures	2D	3D	3Dr	P-value (2D/3D)	P-value (2D/3Dr)
Lumen Volume*	62.81 ± 22.36	59.04 ± 25.51	63.21 ± 27.18	0.16	0.92
Wall Volume*	66.42 ± 19.27	66.41 ± 19.49	64.12 ± 17.00	0.99	0.61
MWT (mm)	1.36 ± 0.40	1.45 ± 0.35	1.35 ± 0.36	0.09	0.44
minLA (mm^2)	19.24 ± 9.51	18.48 ± 10.55	21.14 ± 12.62	0.44	0.1
maxWT (mm)	3.37 ± 1.55	3.79 ± 1.43	2.87 ± 1.70	0.06	0.15

*Units in mm^2/ 2mm slice thickness, 3Dr – Reformatted 3D

Table 3: Comparison of SNR

	2d	3d	Reformatted 3d	P-value (2D/3D)
Lumen SNR	4.52±2.65	5.03±3.08	8.18±5.54	0.16
Wall SNR	13.64±7.35	14.23±8.59	21.90±14.23	0.65
CNR	9.11±9.20	9.20±5.69	8.89±2.68	0.94

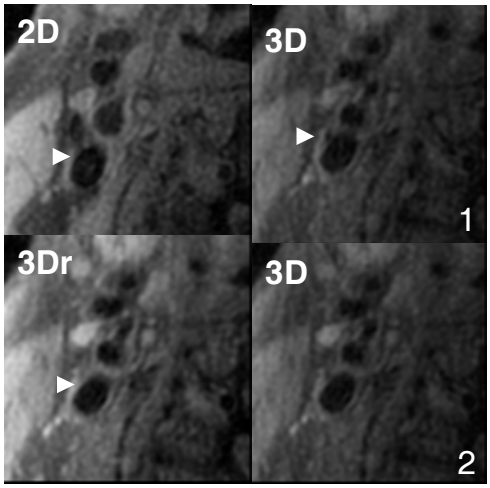

Figure 2: Small plaque calcifications (arrow) were clearly seen on 3D (top right) compared to 2D (top left). The calcificate was not visible on 3D reformatted to match 2D (bottom left). The change in shape of the calcificate is clearly seen moving from slice to slice on 3D (right column)

References

[1]Yarnykh VL et al, ISMRM, 2005 [2] Crowe LA, 2003 [3] Luk-Pat GT, MRM, 1999 [4] Yarnykh VL, Current Protocols in MRI, 2004 [5] Han C IEEE-TIP,2001 [6] Bland BMJ 1996