Scan-Rescan Reproducibility of Carotid Geometric Parameters using Bright Blood MRI at 3.0T

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Introduction: Atherosclerotic lesions in humans commonly develop at arterial branch sites, characterized by low and oscillating shear stress [1,2]. The strong dependence of flow parameters on lumen geometry suggests that lumen geometry alone could provide similar information about the risk of plaque development [3] to the one provided by flow features. Lumen geometry can be assessed on either bright blood or black blood MRI [3]. Reduction of plaque mimicking artifacts through specialized black blood preparations [4] provides smaller longitudinal coverage, requires specialized coils for high SNR, is time consuming and is less widely available compared to bright blood techniques such as 3D-TOF. In mild to moderate atherosclerosis, 3D-TOF may suffice for lumen delineation. However, the ability of 3D-TOF to reliably and reproducibly measure carotid geometric parameters is yet to be investigated. The purposes of this study are: 1) To evaluate inter-scan reproducibility of geometric parameter measurements of carotid atherosclerosis using 3D time-of-flight (TOF) and black-blood sequences at 3 T; and 2.) To determine whether a bright blood sequence (3D TOF) can provide reproducible measurements of geometric parameters similar to or better than a black blood sequence.

Materials and Methods: Carotid imaging: A total of 20 patients (18 male, age range = 54-88; mean age = 71.05±9.33years) with carotid stenosis > 15% identified by duplex ultrasound were scanned twice, two weeks apart, on a 3T MRI scanner (Achieva; Philips Medical Systems, Best, Netherlands) using a bilateral four-element phased-array surface coil. The protocol included 3D TOF and MSDE proton density (PD). Detailed imaging parameters were: 3D-TOF: FEE, TR: 20msec, TE: 4msec, field of view (FOV) =140X140mm, Matrix =256X256, 1mm slice thickness, 48 slice. MSDE-PD: TR: 4000msec, TE: 8.5msec, echo train length (ETL) = 12, FOV = 140X140mm, Matrix = 256X256, 2 mm slice thickness, inter-slice spacing = 0 mm, 16 slice, motion sensitizing gradient strength 15 mT/m, duration 4.5 msec, mI =715 mTms2/m.

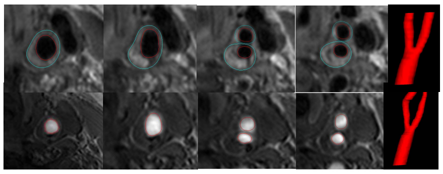


Figure 1. An Example of Carotid Reconstructed from Llumen Contour Based on MSDE (upper raw) and 3D-TOF images (lower raw)

Image review: The artery with the most plaque was reviewed on 3D-TOF and MSDE-PD independently. Lumen boundaries were outlined using a custom-designed, semi automated software (CASCADE). A 3D reconstruction of lumen geometry was made from lumen contours (Figure. 1).

Quantification of geometry: Carotid artery geometric parameters (bifurcation angle, internal carotid angle (ICA), external carotid angle (ECA), ICA planarity, ICA tortuosity, and ECA tortuosity) were measured using a public domain software: VMTK [5] by a separate reader (Fig. 2). All geometric parameters were defined as per Steinman et al. [3].

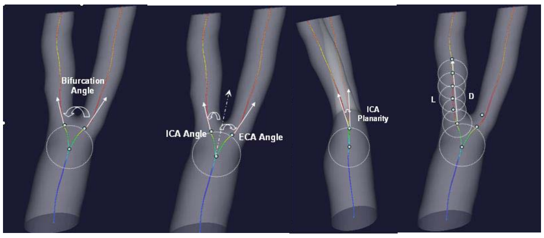


Fig. 2. Definition of Carotid Geometric Parameters (L: length of centerline, D: straight line between the same two points, vessel tortuosity was defined as L/D-1) [3].

Statistical Analysis: Intra-class correlation (ICC) was performed to determine the reproducibility of geometric parameters on 3D TOF and MSDE and to evaluate the agreement between measurements from 3D TOF and MSDE. A paired t-test was used to examine bias between 3D TOF and MSDE. Bland-Altman plots were used to investigate the relationship between the interscan variation and the magnitude of the measurements. A *P*-value<0.05 was considered statistically significant.

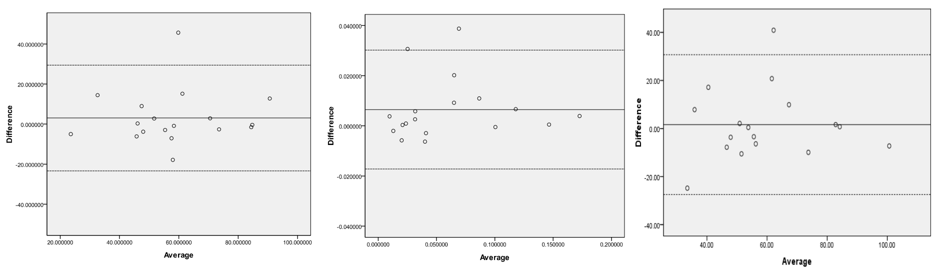
Table 1. Scan-Rescan Reproducibility Results for Carotid Geometric parameters Measurement

	ICC	
	TOF	MSDE
Bifurcation angle	0.85 (0.62-0.95)	0.90 (0.74-0.97)
ICA angle	0.94 (0.84-0.98)	0.84 (0.57-0.94)
ICA planarity	0.87 (0.65-0.95)	0.71 (0.25-0.89)
ECA angle	0.90 (0.73-0.96)	0.78 (0.41-0.92)
ICA tortuosity	0.83 (0.54-0.93)	0.94 (0.85-0.98)
ECA tortuosity	0.98 (0.94-0.99)	0.89 (0.71-0.96)

Table 2. Inter-scan Reproducibility Results for Carotid Geometric Parameters Measurement

	TOF vs. MSDE	
	ICC	*P* (paired t-test)
Bifurcation angle	0.92 (0.76-0.97)	0.654
ICA angle	0.89 (0.69-0.96)	0.199
ICA planarity	0.66 (0.05-0.88)	0.131
ECA angle	0.80 (0.45-0.93)	0.558
ICA tortuosity	0.83 (0.53-0.94)	0.273
ECA tortuosity	0.89 (0.68-0.96)	0.337

Results: After exclusion of images with poor image quality, 18 arteries were available for analysis. Scan-rescan and interscan reproducibility are shown in Table 1 and 2 respectively. There was no significant difference between 3D TOF and MSDE for any geometric parameter (Table 2). Bland-Altman plots for interscan measurements (Fig. 3) showed no significant bias and no significant correlation between bias and mean for both 3D TOF and MSDE.



TOF MSDE TOF vs. MSDE

Fig. 3 Bland-Altman Plots for Bifurcation Angle (°) from 3D TOF, MSDE and 3D TOF vs. MSDE.

Discussion and Conclusion: The results show similar reproducibility for carotid geometric parameters measurements using bright blood or black blood MR images. This suggests that 3D TOF images at 3T can be used for reproducible measurement of geometric parameters of the carotid artery for use in longitudinal studies. Furthermore, the larger coverage of 3D TOF may also be useful for future evaluation of flow parameters associated to plaque progression and rupture using computational fluid dynamics (CFD).

Reference: [1] Malek AM., et al. JAMA.1999; 282:2035-2042 [2] Schulz U., et al. Stroke. 2001; 32: 2522-2529 [3] Thomas JB., et al. Stroke. 2005;36:2450-2456 [4] Wang J., et al. Magn Reson Med. 2007; 58: 973-981 [5] www.vmtk.org