Reproducibility of semi-automated measurement for carotid arterial distensibility using CINE MRI at 3T

G. Canton[1], J. Wang[2], L. Dong[1], W. S. Kerwin[1], and C. Yuan[1]
[1]Radiology, University of Washington, Seattle, Washington, United States, [2]Clinical Sites Research Program, Philips Research North America, Briarcliff Manor, New York, United States

Motivation

Atherosclerotic plaque formation, evolution, and rupture are known to be associated with the mechanical stresses that act on or within the arterial diseased wall (1,2). Accurate patient-specific stress analysis can provide critical information on the understanding of plaque evolution and, most importantly, mechanisms of plaque rupture. MRI-based fluid-structure interaction (FSI) models of carotid atherosclerotic plaques have been shown to be a promising tool to provide such information (2-4). The validity of these models, however, relies on assumptions of the vessel wall mechanical properties since no *in vivo* measurements are available. In order to overcome this limitation, there has been an increasing effort in recent years to measure wall mechanical properties, such as stiffness, *in vivo* using both MR and US imaging techniques (5-6). Wall distensibility (relative area change for a pressure increment) is one of the indexes used to measure arterial wall stiffness (7).

For MRI, the carotid arteries have been the major focus of vessel wall imaging and FSI model development (3,4). Unfortunately, although wall distensibility has been extensively validated in the aorta (8), the ability to reliably and reproducibly measure carotid distensibility has not been investigated.

Objective

The aim of this study was twofold: to determine the inter-scan reproducibility of distensibility measurements at the common and internal carotid arteries using CINE MRI at 3 T; and to evaluate the different mechanical behavior of these two arterial segments by comparing their wall stiffness.

Methods

Carotid Imaging: Five healthy volunteers (4 male, 1 female, age range: 26–34 years) were imaged twice (mean time difference between scans: 7.5 hours) using a 3.0 T clinical whole-body scanner (Philips Achieva, R2.6.1, Best, the Netherlands) with a 4-channel custom-designed carotid coil. MR images were acquired in the axial plane and centered at the left carotid bifurcation. A CINE sequence was used to achieve multiphase (30 per heartbeat) imaging with retrospective ECG gating. Detailed imaging parameters are: TR/TE 7.8/4.9ms, FA 30°, FOV 160x160, pixel 0.8x0.8mm^2 (interpolated to 0.31x0.31), slice thickness 2mm, 3 slices were acquired with 8mm gap to cover common, bifurcation and internal segments on both sides (total imaging time: 1min 29sec).

Common and Internal Carotid Artery Distensibility: A semi-automatic MATLAB-based program (Matlab, R2007b, The Mathworks, Inc) was used to detect the luminal boundary on all phase images at the locations above (internal carotid artery) and below (common carotid artery) the bifurcation. Maximum and minimum luminal area – corresponding to systole and diastole, respectively; were determined from the area measurement along the cycle (30 phases). Pulse pressure was measured from both arms and the mean value was calculated for each volunteer. Common and internal carotid arteries' distensibility was then calculated as $(\Delta A/A_s)/\Delta P$, where ΔA is the area change between systole and diastole, A_s is the luminal area at peak systole, and ΔP is the arm pulse pressure (P_s- P_D).

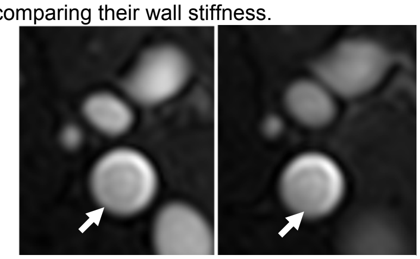

Fig 1. CINE image of a common carotid lumen (arrow) at peak systole from two scans with acquisition gap of 3.47 hours.

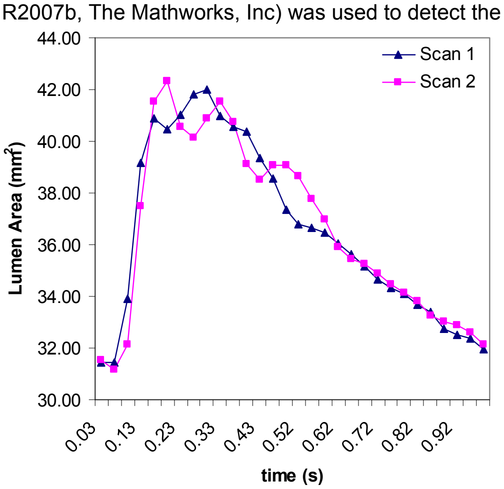

Fig. 2. Comparison of common carotid luminal area change along the cardiac cycle between two scans from one of the volunteers.

Statistical Analysis: Statistical analysis was performed using SPSS (SPSS 12.0, Apache Software Foundation). Intra-class correlation was performed to determine the reproducibility of the measurements at the common and internal carotid arteries. Comparison between common and internal carotid arteries' distensibility was made by paired-samples t-test.

Results

Twenty locations (two locations above and below the left bifurcation for both sides, two time points, five volunteers) were considered in the analysis. Eighteen locations were used to analyze the interscan reproducibility of carotid distensibility (two locations were excluded due to insufficient coverage on the right side). The mean pulse pressure difference was 42.7±6.7 mmHg. Area measurements (Fig. 1) and the calculated distensibility values for both the common and the internal carotid arteries are summarized in Table 1. There was a good agreement for both area (Fig. 2) and distensibility measurements between the two scans (see intra-class correlation coefficient, ICC, in Table 1). A significant difference (p=0.028) between the distensibility measurements at the common and internal carotid arteries was found.

Table 1. Lumen area measurements and Intra-class Correlation Coefficient.

	First scan, mean±SD	Second scan mean±SD	ICC (95%CI)
Diastolic CCA area (mm^2)	29.03±5	29.4±4.9	0.89 (0.49,0.97)
Systolic CCA area (mm^2)	39.7±8.2	39.0±8.2	0.98 (0.90,0.99)
Distensibility, CCA (10^{-5} Pa^{-1})	4.8±1.25	5.1±9.2	0.92 (0.65,0.98)
Diastolic ICA area (mm^2)	19.07±4.8	19.0±4.5	0.94 (0.72,0.99)
Systolic ICA area (mm^2)	23.7±7.5	25.3±10.4	0.87 (0.42,0.97)
Distensibility, ICA (10^{-5} Pa^{-1})	3.3±1.3	3.9±2.2	0.86 (0.37, 0.97)

CCA: common carotid artery; ICA: internal carotid artery; ICC: Intra-class correlation coefficient.

Conclusion

ECG-gated 3T CINE MRI can reliably measure distensibility in human carotid arteries. The degenerative process of the mechanical properties of the vessel wall with atherosclerosis leads to an increase in the wall stiffness. The ability of CINE MRI to reproducibly measure this property raises the possibility of combining the morphological and compositional assessment with mechanical parameters in a single non-invasive investigation. Furthermore, the significant difference in distensibility at the common and internal carotid arteries, indicates that FSI models could be further improved by incorporating the mechanical properties for the different sections of the modeled arterial wall.

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