Semi-Automated Carotid Arterial Morphometry from Sub-Millimeter Isotropic Spatial Resolution Diffusion-Prepared SSFP Data: A Feasibilty Study

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Introduction: MR imaging techniques that provide for three-dimensional (3D) visualization of the carotid arterial walls with black-blood (BB) image contrast have recently been presented [1-5]. Known limitations of these 3D techniques for carotid arterial wall imaging include: (a) swallowing-induced image artifacts [2] and (b) sub-optimal black-blood image contrast (especially in the carotid bulb) due to difficulties suppressing MR signal from slow/re-circulatory flow patterns with inflow-based BB magnetization preparations [6]. To overcome swallowing-induced motion artifacts and potentially improve BB contrast during 3D MR imaging of the carotid arterial wall, navigator gating of the epiglottis [7] and non-inflow dependent BB magnetization preparations (e.g. diffusion preparation) [8] have been applied.

In the context of carotid atherosclerosis, 3D BB MR imaging may useful for measuring arterial wall and lumen areas, thereby facilitating estimation of plaque burden and percent stenosis. However, the large number of sections acquired during 3D imaging renders manual measurement of wall and lumen areas time-consuming and impractical for routine use. We hypothesize that isotropic spatial resolution BB MR images acquired with a navigator-gated diffusion-prepared imaging sequence may lend themselves for semi-automated measurement of carotid wall and lumen areas.

Methods: A 3D diffusion-prepared segmented steady-state free precession (3D DP-SSFP) sequence [8] was modified to incorporate a navigator, thereby allowing for detection and removal of MR data acquired during a swallow. Experiments were performed on 7 healthy volunteers (age = 27-54 years, weight = 84±9 kg) on a 1.5 T clinical scanner (Sonata, Siemens, Erlangen, Germany). After the carotid arteries were localized, 3D DP-SSFP MR imaging was performed. Scan parameters for the 3D DP-SSFP sequence were: axial slab orientation, isotropic 0.6×0.6×0.6 mm^3 spatial resolution, 4.8-cm-thick slab (80 sections per slab), field-of-view = 115×115 mm^2, matrix = 192×192, repetition time (TR) = 1 s, 65 segments per TR, receiver bandwidth = 565 Hz/pixel, segment TR/echo time = 5.2/2.6 ms, flip = 45°, b-value = 16.5 s/mm^2, slice oversampling = 20%, signal averages = 2, imaging time = 596 s (with 100% navigator efficiency). Sub-millimeter, isotropic spatial resolution was used to provide accurate visualization of the arterial wall of the carotid bifurcation along arbitrary views and precise wall and lumen segmentation. The contrast-to-noise ratio (CNR) between the carotid wall and lumen were measured.

An algorithm inspired from literature on segmentation of 3D carotid ultrasound data [9] was applied to the 3D DP-SSFP images for segmenting the carotid wall and lumen boundaries in a semi-automated manner. Prior to semi-automated segmentation, all 3D DP-SSFP images were interpolated by a factor of 5, averaged with (2-3) adjacent slices, and filtered to reduce image noise. A Sobel edge detection filter coupled with a candidate proximity criterion as described in [9] were used to segment arterial wall boundaries. By use of linear regression analysis, carotid wall and lumen area measurements made with the semi-automated segmentation algorithm were compared those made manually by an experienced user. The within-slice standard deviations for wall and lumen area with the semi-automated algorithm were calculated from 4 repeated segmentations.

Results & Discussion: Navigator efficiency for the 3D DP-SSFP sequence ranged from 92%-100%, corresponding to imaging times between 599-620 s. Images acquired with navigator-gated 3D diffusion-prepared SSFP imaging sequence are shown (Figure 1a and 1b). Black-blood image contrast was observed, however, the carotid wall-lumen CNR was somewhat low (5.2±1.1), likely due to the use of high, isotropic spatial resolution. Results of the computer-assisted segmentation algorithm are shown (Figure 1c). Carotid lumen and wall areas made with the semi-automated algorithm (Figures 2) were strongly correlated to manual measurements (r^2 = 0.99 for lumen area and r^2 = 0.94 for carotid wall area; P < 0.001 for both). Within-slice standard deviations for area measurements of the wall and lumen with the semi-automated segmentation algorithm were 1.49 mm^2 and 0.96 mm^2, respectively. Semi-automated segmentation was approximately 15~20 times more efficient than manual segmentation.

Conclusion: Sub-millimeter isotropic spatial resolution black-blood MR imaging of the carotid arteries is feasible with a navigator-gated 3D diffusion-prepared steady-state free precession sequence. The resulting images lend themselves for time-efficient, computer-aided quantification of carotid lumen and wall areas that are in good agreement with manual measurements.

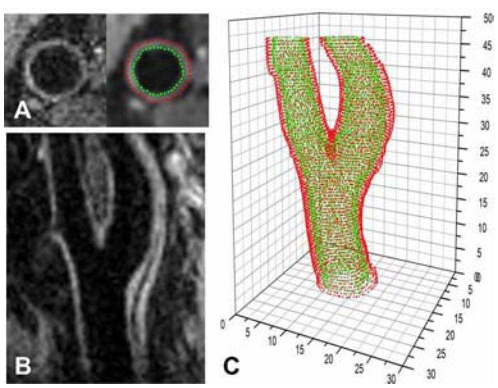

Figure 1. **(a)** *Left*, magnified raw 3D DP-SSFP image of the common carotid artery; *right*, corresponding segmented image. **(b)** Oblique-sagittal multi-planar reformation through the 3D DP-SSFP data set clearly depicts the long axis of the arterial wall. **(c)** Inner (green) and outer (red) carotid wall boundaries generated by the computer-assisted segmentation.

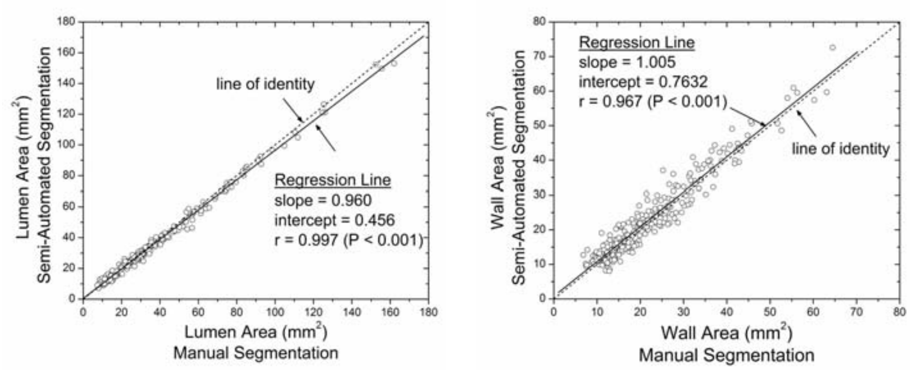

Figure 2. *Left*, scatter plot displaying carotid lumen areas measured with manual and semi-automated segmentation. *Right*, scatter plot displaying carotid wall areas measured with manual and semi-automated segmentation. Strong correlations between manual and semi-automated measurements were observed (P < 0.001).

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