CAROTID GEOMETRY RECONSTRUCTION: A COMPARISON BETWEEN MRI AND 3D ULTRASOUND.

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INTRODUCTION

Image-based CFD has become a popular tool for acquiring in vivo flow patterns and hemodynamic wall parameters. Currently, magnetic resonance imaging (MRI) is most widely used for in vivo geometry acquisition. For superficial vessels such as the carotids and femoral arteries, 3D extravascular ultrasound (3DUS) could be a cost-effective alternative to MRI. Like black-blood MRI, 3DUS can provide information on vessel wall thickness and lumen shape. Using a carotid phantom [1] and in vivo subject-specific data, our combined 3DUS and CFD approach has been shown to be reliable and reproducible.

This study is the first to compare the carotid bifurcations of healthy volunteers reconstructed from black-blood MRI and 3DUS. Geometric differences are believed to have an important influence on hemodynamic parameters such as wall shear stress (WSS), which has been correlated with different stages of atherosclerosis.

METHODS

Black-blood MRI

Nine healthy volunteers, including 8 males and 1 female, aged between 24 and 56, were scanned while lying supine with his/her head held in a straight position. All scans were performed with a Siemens Magnetom Sonata 1.5 T scanner. For each subject, two sets of images were acquired which corresponded to mid-to-late diastole and end-systole. For these *volume selective Turbo Spin Echo (TSE)* images, a true (non-interpolated) resolution of 0.47 x 0.47 mm in plane and a FOV of 120 x 24 mm were typical with 28 slices (2 mm thick). An echo train length of 7 was used to fit the scan within the desired acquisition window (65 ms). For a T_1 weighted image, T_E=9ms and T_R=RR (the interval between consecutive R-waves). Each scan lasted 3-5 minutes, depending on the subject's heart rate. For systolic TSE imaging, a modified sequence with dark blood preparation at the end of the preceding cardiac cycle was used.

Black-blood MRI images were segmented and reconstructed semi-automatically using the region growing method together with the snake model. However, it was necessary to check the semi-automatically segmented images and make some manual adjustment where appropriate, due to acquisition errors inherent to black-blood MRI. The serial 2D contours were then aligned to produce a 3D vessel surface geometry. Smoothing was performed on the vessel centerlines and surface.

3D Ultrasound

The 3DUS system used has been described in detail in [2]. In short, the in-house ECG gated 3DUS scanner (Ascension Technology Inc, Vermont, USA), equipped with a conventional 12/5 MHz broadband linear array transducer (HDI 5000, ATL-Philips Ltd., Bothell, MA, USA) was used to acquire ECG gated transverse images of the carotid bifurcation. An electromagnetic position orientation measurement (EPOM) device, mounted on the probe, recorded the position and orientation of the probe in 3D space. During each scan, the transducer probe was swept slowly over the subject's neck. A series of transverse images captured at mid-to-late diastole were stored digitally on the scanner and later downloaded to a PC to be analyzed off-line.

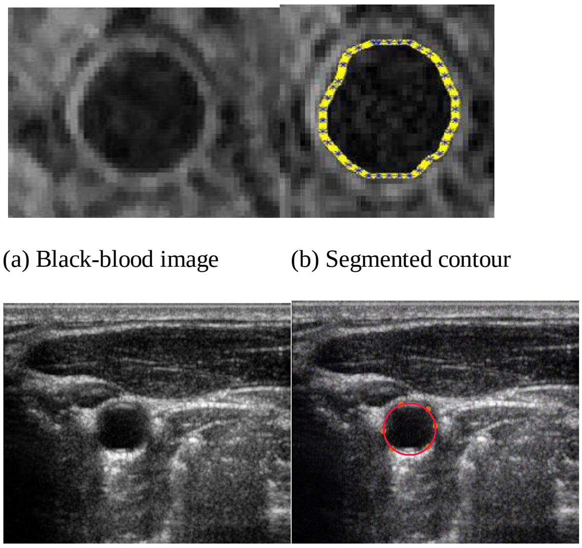
Acquired images were segmented using purpose-built software, which was implemented in MATLAB (Mathworks, Natick, MA). The software was used to manually select points on the vessel wall to which a smooth cubic spline or ellipse was fitted. The delineated contour usually represents the media-adventitia border rather then the lumen, hence needs to be readjusted by subtracting the intima-media thickness from it. The resulted lumen contours, combined with the positioning information from the EPOM device, the 3D geometry of the carotid bifurcation can be reconstructed.

Representative black-blood MRI and 3DUS images acquired from the common carotid artery of one of the subjects are shown in Figure 1. Also given in the figure are segmented contours.

RESULTS

Areas

Lumen areas were calculated along each of the arteries (CCA, ICA and ECA) for all carotid bifurcations reconstructed. The average area was evaluated for each artery generated from the systolic



(a) Black-blood image (b) Segmented contour

(c) 3DUS image (d) Segmented contour

Figure 1. Cropped black-blood MRI image (a) and semi-automatically segmented contour (b), as well as 3DUS image (c) and manually segmented contour (d), from the right common carotid artery of subject 2.

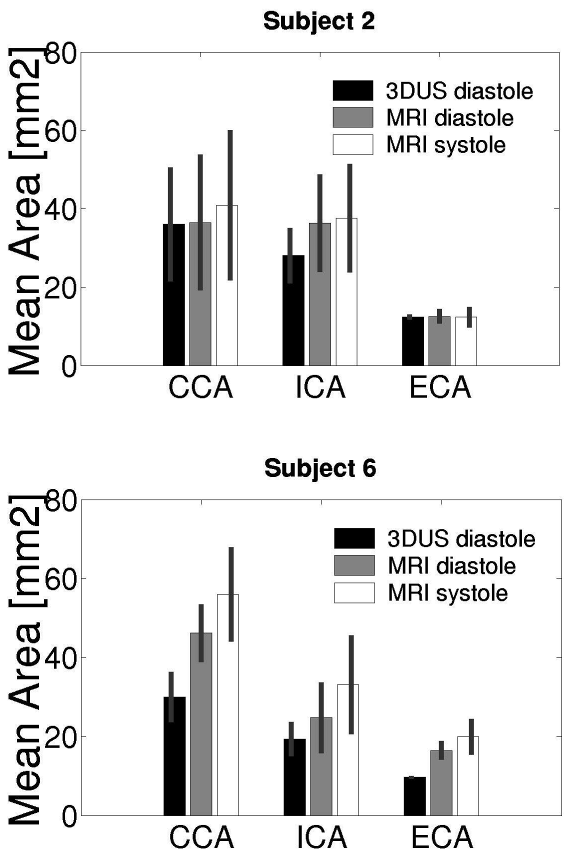


Figure 2. Average lumen area in CCA, ICA and ECA, derived from 3DUS (diastolic), diastolic black-blood MRI and systolic black-blood MRI for subjects 2 and 6, respectively.

black-blood MRI images, diastolic black-blood MRI images and 3DUS images (diastolic), respectively. Comparisons of average lumen areas derived from these three sets of images are given in Figure 2 for subjects 2 and 6, representing a good and an average case. It was found that areas estimated from diastolic black-blood MRI images were generally larger than those from 3DUS (also at mid-to-late diastole).

Centerlines

Comparisons of vessel centerlines were made between diastolic black-blood MRI and 3DUS for all subjects. By performing single value decomposition on the matrix formed by all points on the centerline, a quantitative measure of bifurcation non-planarity can be derived. Large differences in non-planarity between the two imaging methods were noticed.

DISCUSSION AND CONCLUSION

Our results suggest that there is a good agreement in lumen areas derived from the black-blood MRI and 3DUS images, but significant differences in centerline exist. When making these comparisons, it is important to note that image segmentation and geometry reconstruction were performed differently with the two different types of images. We believe that it would be impractical to adopt a unified approach, due to differences in image quality and data format. It should also be mentioned that it is almost impossible to scan a subject in exactly the same head and neck position during the MRI and 3DUS sessions. Especially in a 3DUS scan, the operator might have to reposition the subject's neck in order to gain more coverage of the carotid branches and/or better ultrasound images. This will inevitably change the vessel curvature, hence the shape and non-planarity of the centerlines.

Overall, 3DUS has proved to be able to generate 3D in vivo carotid geometries which are suitable for CFD simulations and are comparable to those reconstructed from MRI. However, 3DUS still has a number of limitations, such as limited field of view due to the presence of the jaw bone and relatively high operator dependence as a result of manual image segmentation. Nevertheless, with the current level of accuracy and reproducibility achieved and with further improvement in imaging and automation of the segmentation/reconstruction procedures, 3DUS has a great potential to become a relatively inexpensive, fast and accurate alternative to MRI for CFD-based hemodynamics studies of superficial arteries.

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