Ultrasound-based 3-D mechanical modeling of the carotid artery and vulnerable plaques

J. de Ruijter, F. N. van de Vosse, M.R.H.M. van Sambeek, R. G. P. Lopata

Background, Motivation and Objective

Patients with a severely stenosed carotid artery are at risk of stroke. Carotid endarterectomy is performed to prevent possible plaque rupture. However, only one out of six patients benefits from this risky intervention. To improve upon clinical decision making, patient-specific modelling of the carotid artery bifurcation has been proposed, including the assessment of wall (shear) stress and material properties. In this study, patient-specific models of the carotid are introduced based on 3-D ultrasound (US).

Statement of Contribution/Methods

A high resolution 3-D geometry of the carotid artery is acquired using freehand US in combination with a probe tracking device. To improve contrast, 2-3 slow (± 5 mm/s) sweeps from different angles were made along the patient's neck (**Fig 1A**). The voxel volume was reconstructed using a pixel based method, the gradient in the original image determined the weight of each pixel contributing to the voxel. The holes were filled using convolution with a Gaussian mask. The 3D geometry was reconstructed using an automated segmentation algorithm described in previous work. A hexahedral mesh was generated from the ultrasound data, the patient-specific wall thickness is based on a local IMT measurement, increased by 30% for the adventitial layer which cannot be depicted from the US. The wall distensions were estimated locally, using interpolation on the diastole and systole frames from the segmented sweep data (**Fig 1C**). An iterative FE method was used to estimate global material properties of the arterial wall. In this method, the error between the measured and simulated displacements (**Fig 1B**) was minimized by adjusting the material properties iteratively. The method was tested on healthy volunteers (n=5) and patients that were included for carotid endarterectomy (n=3). Automated segmentation was compared with manual segmentations by three sonographers. Finally, finite element analysis was performed to estimate the wall stress in the carotid artery, using the measured geometry, brachial arterial pressure, and wall motion as input.

Results, Discussion and Conclusions

The estimated 99 percentile wall stresses and the estimated shear moduli (G=140 kPa) were within the range found in literature for young adults. In future work, this methodology will be extended to an inverse method to possibly identify the presence of lipid in the arterial wall.

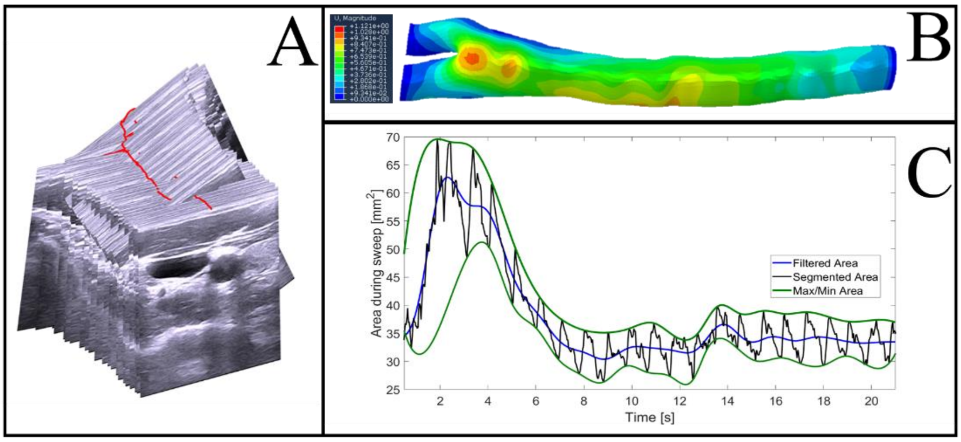

Fig. 1. Probe tracked freehand ultrasound images translated to 3D space (A). FE simulation based on ultrasound images, magnitude of displacements in mm (B). Segmented sweep area in black, area after filtering in blue, estimated diastole and systole areas in green (C).