A Deep Learning-Assisted Ultrasound Imaging Workflow for Patient-Specific Carotid Artery Modeling and Phantom Fabrication

Background, Motivation and Objective

Hemodynamic analysis of the carotid artery is critical for assessing cerebrovascular risks. While carotid ultrasound offers patient-specific geometry for integration into physical phantoms or computational models to assist in prognostic tasks, free-hand scanning introduces geometric inaccuracies that compromise 3D reconstruction. This study thus aims to develop an integrated pipeline combining *in vivo* ultrasound imaging, phantom fabrication, and hemodynamic simulations to provide a comprehensive tool ultimately for stroke risk assessment.

Statement of Contribution/Methods

A custom ultrasound scanning apparatus with three universal joints was developed to stabilize a linear array probe during transverse plane imaging of the human carotid artery (Fig. (a)). The proximal joint enables controlled probe translation, while the distal pair adapts to vertical neck contours and constrains other movements. A foundational model MedSAM was adapted for lumen segmentation. To address anatomical complexity and natural pulsation in the common and bifurcated segments, we enhanced MedSAM by designing 1) adaptive prompting to track inter-frame lumen changes and 2) a bifurcation detection module using aspect ratio (Fig. (b)). The segmentation results were reconstructed into a patient-specific 3D carotid artery model. *In vivo* arterial wall stiffness and blood flow were quantified using shear wave imaging and Doppler ultrasound, respectively. Patient-specific fluid-structure interaction simulation with physiological parameters was developed in COMSOL. Patient-specific PVA hydrogel phantoms replicating *in vivo* stiffness were fabricated using a 3D-printed mold with a water-soluble PVA core (Fig. (c)).

Results/Discussion

The scanning apparatus corrected free-hand misalignment, while our automated segmentation reduced user dependence with a 0.102 Dice score improvement. The phantom (Fig. (d)) had an average wall thickness of 2.6 mm with lumen diameter variations (1.19 ± 2.28 mm vs. B-mode) and Young's modulus of 77 kPa. The flow pattern in the fluid-structure simulation agreed well with that quantified by Doppler ultrasound, showing a 7:3 ICA/ECA flow ratio and flow separation at the bifurcation site (Fig. (e)). Ongoing works focus on reproducibility analysis and development of pathological arterial wall and flow properties.