PERSONALIZED FINITE ELEMENT ANALYSIS OF LARGE ABDOMINAL AORTIC ANEURYSMS USING MULTI-PERSPECTIVE 3D+T ULTRASOUND

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Introduction

The need for rupture-preventing surgical repair of abdominal aortic aneurysms (AAAs) is currently based on the AAA diameter. However, a more patient-specific measure is required, as some AAAs rupture before the diameter threshold is reached, while other larger AAAs stay stable. With time-resolved 3D ultrasound (3D+t US) combined with finite element analysis (FEA), the mechanical properties and wall stress of the AAA can be obtained, providing additional rupture risk indicators.

Due to the limited field of view (FOV) of 3D+t US, larger AAAs cannot be captured in a single image. Previous research has focused on combining geometries from multiple US images for FEA [1], but model personalization with mechanical parameters derived from multi-perspective ultrasound has not yet been performed. The goal of this study is to perform mechanical characterization and wall stress analysis of large AAAs by temporally and spatially registering multiple 3D+t US images.

Methods

Sets of proximal and distal 3D+t US images of 7 AAA patients were automatically segmented with an in-house segmentation algorithm. Temporal registration was performed by tracking the aortic wall over different time frames [2], followed by reordering the frames in both the proximal and distal datasets into a single artificial cardiac cycle (Figure 1A-C). Diastolic and systolic time frames were selected for both images. The diastolic images were spatially registered using phase-only correlation [2-3] and the segmentations were combined (Figure 1D-F). The diastolic-to-systolic displacement was determined by performing speckle tracking on the individual images and combining the resulting displacements.

The combined diastolic geometry was converted to a prism mesh with 2 mm wall thickness. The shear modulus was estimated based on a FEA updating approach in Ansys, by adapting the shear modulus (G) until the displacements in the FEA matched the speckle tracking-derived displacements. For validation, this process was also performed on the proximal and distal images separately.

Results

Temporal and spatial registration of proximal and distal images was feasible for all 7 patients, leading to a 20-40% increase in FOV. Preliminary results comparing the shear moduli based on the separate and combined images (Figure 2) show that for some patients (2 and 3) these values are very similar, while for other patients differences up to 4MPa are found, indicating possible local variations in material properties.

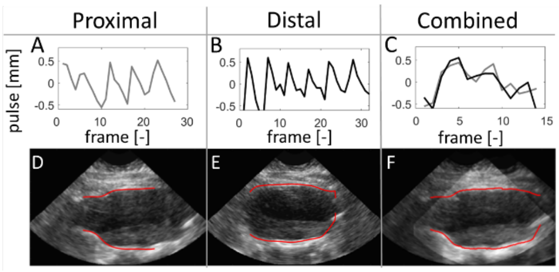

Figure 1: Temporal (A-C) and spatial (D-F) registration of a proximal and distal 3D+t US images, with the segmentations marked in red.

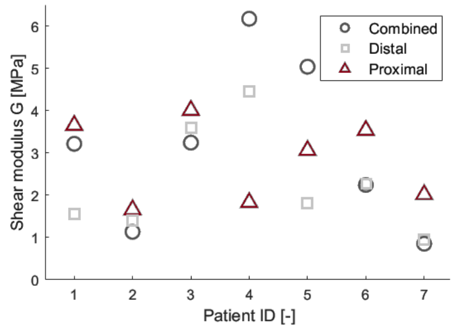

Figure 2: Patient-wise shear moduli based on iterative FEA from proximal, distal, and combined images.

Discussion

This work shows the feasibility of patient-specific mechanical characterization and wall stress analysis of large abdominal aortic aneurysms based on 3D+t US. This is a step towards a more patient-specific non-invasive rupture risk indicator, which is suitable for large AAAs. Next steps are analysis of the local displacements, and application of the method in a longitudinal study, investigating the progression of the material properties and wall stresses with AAA growth.

References

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