ULTRASOUND-BASED FSI MODELING OF ABDOMINAL AORTIC ANEURYSMS INCLUDING PATIENT-SPECIFIC VELOCITY PROFILES

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Introduction

Current abdominal aorta aneurysm (AAA) risk assessment is based on a 'one size fits all' approach. However, both wall mechanics and hemodynamics are highly dependent on the AAA geometry. Therefore, a patient-specific (PS) risk assessment is required, based on fluid-structure interaction (FSI) models [1]. Time-resolved 3-dimensional ultrasound (3D+t US) is the preferred image modality to extract the patient-specific geometry, since it is safe, fast and affordable. Furthermore, the hemodynamics may highly depend on the prescribed inlet velocity profile. Therefore, this study aims at obtaining PS inlet velocity profiles to employ in highly personalized FSI simulations.

Methods

Doppler acquisitions were executed proximal to the aneurysm region in 6 patients. Pulsed-wave Doppler was used to acquire the velocity profile over time and Color Doppler was used to obtain the velocity profile over the cross-section by extracting the color gradient (Fig 1). Furthermore, Doppler imaging enables the use of a PS heart rate, inlet radius and inlet length. FSI simulations employing generic and PS flow parameters were performed and the differences in hemodynamics and wall mechanics in the aneurysm region were evaluated. In an ongoing study, the US Doppler flow parameters are validated with the use of 2D Phase-Contrast MRI in healthy volunteers.

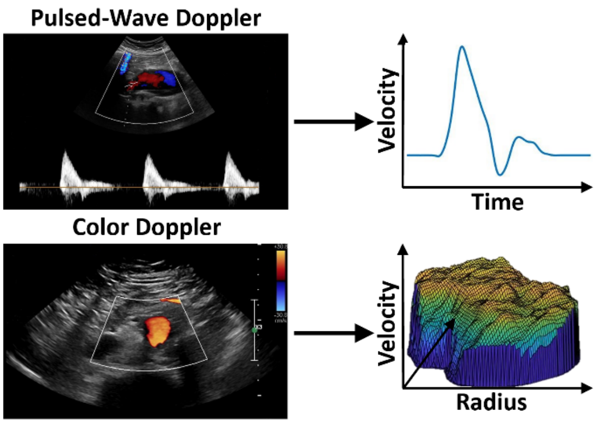

Figure 1: pulsed-wave (top) and color (bottom) Doppler acquisitions used to extract the velocity profile over the time and cross-section, respectively.

Results

Differences up to 500% in time-averaged wall shear stress (TAWSS, Fig. 2) were observed when the flow parameters were made PS, mainly explained by the differences in peak and mean flow. Furthermore, the spatial TAWSS patterns changed significantly. For the oscillatory shear index (OSI), large differences in spatial patterns were detected, caused by the skewness of the PS velocity profile over the radius. Finally, the wall stress values were significantly influenced by the PS flow parameters. Preliminary validation results are shown in Fig. 3, which shows good agreement of US- and MRI-derived velocity profiles over time.

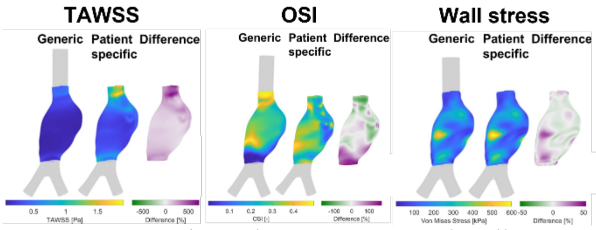

Figure 2: FSI-derived TAWSS, OSI and wall stress values for generic and PS simulations, and the differences in the AAA region.

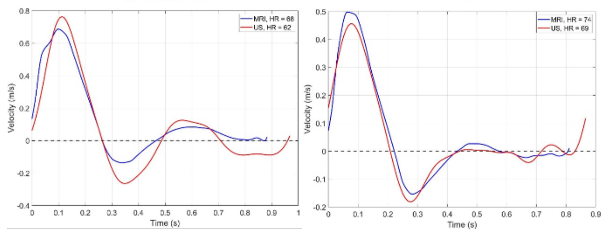

Figure 3: US (red) and MRI (blue) derived velocity profiles over time for two healthy volunteers.

Discussion

This study showed the large influence of inlet flow parameters on hemodynamics and wall mechanics of the AAA and therefore stresses the need for a personalized approach. The validation study will be extended to include patients. In future studies, the obtained framework will be further personalized using 3D+t US speckle tracking for wall motion, and validated with the use of 4D flow MRI. The envisioned framework for personalized 3D+t US-based FSI simulations paves the way for longitudinal studies on AAA development, growth, and rupture risk.

References

1. Fonken et al., Front. Physiol., 1255, 2021.

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