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ABSTRACT BOOK

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BIOMECHANICAL MODELLING OF THE AORTA IN ADULT ZEBRAFISH

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Introduction

Zebrafish models are used to study the fundamental mechanisms of cardiovascular disease [1]. The importance of mechanobiology in development and (patho)physiology suggests that it might be crucial to integrate biomechanical aspects of the zebrafish circulation. A few recent studies exploit the optical transparency of developing zebrafish and describe the cardiovascular biomechanics at this stage [1,2]. Imaging options in adult zebrafish, no longer transparent, are more limited and models to evaluate the cardiovascular biomechanics at adult stages are lacking. We combine high-frequency echocardiography and synchrotron X-ray imaging to demonstrate the feasibility of finite element modelling of the aorta in adult zebrafish.

Methods

First, *in vivo* high-frequency ultrasound measurements (VEVO 2100 ultrasound machine and VEVO MS 700 probe) of n=5 wild-type, 13 months old adult zebrafish were acquired. Afterwards, *ex vivo* phase-contrast synchrotron X-ray imaging of the same samples was performed at the Paul Scherrer Institute in Villigen, Switzerland. Synchrotron scan settings were based on [3]. Starting from the resulting synchrotron image stacks, Mimics 24.0 was used for semi-automatic segmentation and 3D reconstruction of blood and vessel wall volumes. Three cardiac cycles were simulated in finite element software COMSOL Multiphysics v5.6, both in computational fluid dynamics (CFD) and fluid-structure interaction (FSI) studies. Blood was modelled as an incompressible, Newtonian medium (ρ=1060 kg/m³, μ=2.2 cP) and in FSI studies, the vessel wall was modelled as an incompressible, Neo-Hookean material (ρ=1000 kg/m³, μ=30 kPa). Inlet flow profiles were based on the ultrasound measurements while resistive outlet conditions were tuned to approximate equal outflow from all gill branches.

Results

Accurate, sample specific aorta geometries could be obtained from the synchrotron scans. Other structures such as the bulbus arteriosus (the pear-shaped buffer in between the ventricle and aorta) could also be segmented and 3D reconstructed form the synchrotron images. The semi-automatic aorta segmentation is illustrated in Figure 1 (top). Computational results such as velocity (max. ±200 mm/s), pressure (max. ±6 mmHg), wall shear stress (max. ±30 Pa) and first principal stress (max. ±30 kPa) were fairly consistent across all five samples. For one sample, wall shear stress at systolic peak is presented in Figure 1 (bottom).

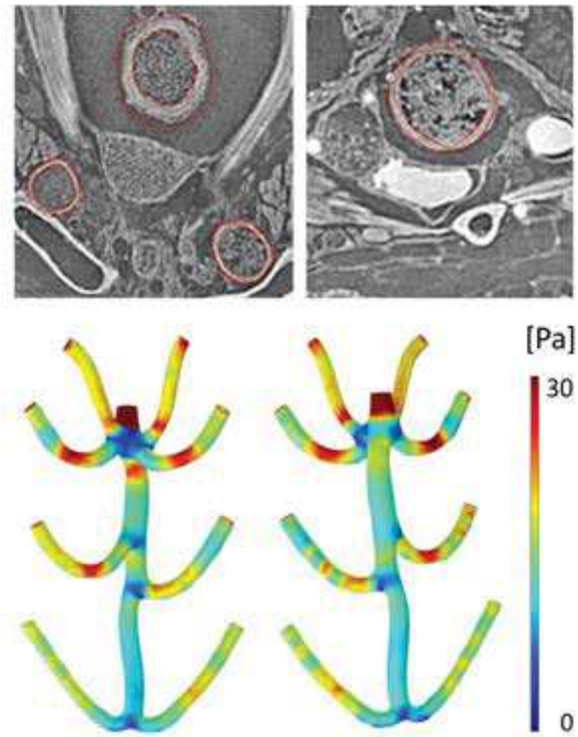

Figure 1: Top - Synchrotron images of the aorta region. Red tracings indicate the segmentation of blood and vessel wall areas for a proximal (left) and distal (right) cross section of the aorta. Bottom - Wall shear stress results from an FSI study at systolic peak. A ventral (left) and dorsal (right) view is provided (the vessel wall is not visible). The diameter of the aorta is about 0.1 mm.

Discussion

For the first time, biomechanics in the aorta of adult zebrafish can be evaluated. For now, most emphasis should be put on overall patterns rather than exact absolute values. Note for example that the region of lowest wall shear stress, i.e., the ventral side of the most proximal branching region, is also the location of highest principal stress in the vessel wall for all samples. The same modelling workflow can be applied in zebrafish models of cardiovascular disease and the wild-type results provide a baseline in such studies.

References

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