Biomechanics of cardiovascular tissues 1

Cardiovascular
Time: 14:30 - 16:00
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Posters for this session are on display on Monday, 9th July in Liffey A.

Chairs: Jay Humphrey and Jacopo Ferruzzi

O0015 - Fluid-structure interaction in cardiovascular biomechanics: yes (because) we can ?

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Abstract

There is much to be gained from patient-specific computational models complementing medical imaging and clinical data. Furthermore, recent examples from successful spin-off companies have learned that biomechanical modelling is no longer a priori restricted to the academic environment, provided that the output of the model pertains to the clinical setting and the clinician and that a workflow can be defined that is compatible with the clinical decision process. This also often implies efficient data handling and optimizing model complexity without compromising the validity and accuracy of the solution. In cardiovascular biomechanics, involving blood flow in passively or actively deforming structures, a choice that often needs to be made is whether or not to account for the fluid-solid interaction (FSI), or to what degree to account for it. Setting up an FSI problem is not a trivial task. As for any computational study, the wrong (combination of) boundary conditions may lead to non-physical and/or non-physiological results which may not always be appreciated from an analysis of the calculated flow field, but will certainly appear in the pressure field (which is only seldomly reported in FSI studies). The optimal strategy to set up the problem depends on the desired output of the model and the focus of the study. When it is the aim to account for the impact of the kinematics of cardiovascular structures on the blood flow, the structural problem can probably be solved with simplified constitutive equations, or the motion of (part of) the boundaries of the computational domain may even be imposed, provided that sufficient care is taken to ensure consistency between the imposed motion and the inflow- and outflow boundary conditions. The question whether full FSI simulations are always warranted when studying tissue biomechanics under a hemodynamics load is probably even more pertinent. In this presentation, using examples from my own research group and from literature, a review will be given of possible strategies to solve the fluid-structure interaction problem in cardiovascular biomechanics. The state-of-the-art and added value of fluid-structure interaction simulations will be addressed and discussed.

O0017 - Unravelling the aortic microstructure: synchrotron-based quasi-static pressure inflation of the mouse carotid artery

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Abstract

The contribution of the aortic microstructure to the mechanical behavior of the aortic wall is poorly understood. Several high-resolution techniques have been proposed to visualize elastic lamellae or collagen fibers, but most have a limited field of view and are challenging to perform in pressurized conditions. In recent experiments we visualized the micro-structure of mouse aortas using phase propagation imaging – a synchrotron-based technique that yielded 3D images on which separate lamellar layers could be identified (unpublished data, manuscript in preparation). In the experimental study that is presented here we used phase propagation imaging to quantify, for the first time, the unfolding of aortic lamellae during quasi-static pressure inflation experiments. Six wild type and six ApoE$^{-/-}$ mice, all male and on a C57Bl6/J background, were used for this study. The left carotid artery was harvested immediately after sacrifice and mounted on a dedicated synchrotron-compatible pressure inflation device. During the experiment pressure was increased quasi-statically with a syringe pump and maintained at a constant level during each imaging step. After two initial loops of 0-120 mmHg to precondition the vessel, scans were taken at pressure levels of 0, 10, 20, 30, 40, 50, 70, 90 and 120 mmHg while the axial stretch was kept at the in vivo value. Phase propagation was performed at 25m source-to-sample distance, 25 cm sample-to-detector distance and at 21 keV. A scientific CMOS detector (pco.Edge 5.5) was used in combination with a 4x magnifying visible-light optics and a 20 µm thick scintillator. The effective pixel size was 1.625 x 1.625 µm^2. During post-processing the images were skeletonized and a bi-directional graph was generated in Matlab. Using a modified Dijkstra algorithm in which lower weights were assigned to the edges closest to the center of the vessel, we created a Matlab-based algorithm that allows us to automatically segment the main micro-structural features each of the three lamellar layers in the carotid artery. The algorithm exploits the edge connectivity and the shortest path constraints, and weights of edges belonging to the shortest path are subsequently increased order to allow for the detection of subsequent layers. After filtering and de-trending the signal, the undulation of each layer was quantified from the prominence of the peaks in the signal. Both in ApoE$^{-/-}$ and wild type mice we were able to quantify how the increased straightening of the lamellar layers in response to the increasing pressure related to the change in vessel diameter that is quantified in traditional biomechanical experiments. In future work we intend to use the synchrotron-compatible pressure-inflation device in order to experimentally determine the micro-structural material properties of aortic lamellae and the interlamellar space.