The Evolution of Computational Hemodynamics as a Clinical Tool in Decision Making, Patient Specific Treatment and Clinical Management. Part II

This journal issue concludes the two-part Special Issue on the application of computational hemodynamics in clinically relevant problems, in an effort to disseminate the current advances in the field and to stimulate discussion on future research directions. The Special Issue Call for Papers had an overwhelming response, reflecting the richness of techniques, methodologies and applications of computational hemodynamics to enhance the comprehension of a large variety of problems.

In summary, it is well accepted that the hemodynamic environment plays a key role in the initiation and progression of blood vessel disease, in short and long term outcome of blood recirculating devices, and in the outcome of surgical strategies. Computational methods, by virtue of user controlled resolution, can provide quantitative, specific-to-subject information still not achievable with current imaging technologies, allowing the evaluation of normal and pathological functions, devices, and treatments. In this sense, computational hemodynamics has the capacity to enhance clinical diagnosis, prognosis and treatment. Specifically, it contributes to: (1) Enriching the knowledge of basic relationships between local hemodynamics and focal disease, testing quantitative hypotheses in controlled conditions; (2) Supporting decisions in the clinical practice, improving therapeutic treatments and surgical strategies; (3) Designing, optimizing and evaluating the performance of implants and devices.

In this second Issue, we aim again in presenting the progress done by the research community to enhance and implement the potential features of computational hemodynamics, thus contributing to its translation into clinical practice, and to increase the awareness of the utility of hemodynamic modelling. The availability of advanced computational technology and efficiency of tools has allowed the assimilation of more clinical data from clinical imaging and other technologies into the computational framework and has upgraded computational hemodynamics modelling from image-based to patient-specific. It is expected that this ongoing effort will further be expanded in the near future to: (1) Include more cardiovascular applications, (2) Accelerate

the rate of building large datasets, (3) Provide quantitative data useful for proof-of-concept and longitudinal studies on clinically relevant cohorts, and (4) Provide mechanistic explanations to clinical observations.

We reiterate here the belief that the possibility to computationally explore a wide range of clinical solutions will enable clinicians gain insights, develop intuitions, and provide constructive feedback and guidance for the development of more representative models. The development of tools for patient-specific simulations will advance therapeutic planning, thanks to the possibility of investigating pre-operative conditions, to virtually explore post-operative scenarios and predict the outcome of therapeutic interventions.

Our firm conviction is that this second part of the Special Issue provides a clear proof of evidence of the potential of computational hemodynamics in terms of its capability to provide mechanism-based insights for the study of the onset and progression of cardiovascular disease, patient-specific prediction

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of therapeutics outcome, and support in the design and optimization of cardiovascular devices.

Specifically, the hemodynamic baseline condition within an arteriovenous fistula is predicted by Browne *et al.*, validating computationally-predicted pressure drops across the fistula with *in vivo* measurements. The effect of head posture on the vertebral artery geometry and hemodynamics is investigated by Aristokleous *et al.* In the paper by Trachet *et al.*, a realistic fluid structure interaction model is developed to study wall shear stress and principal stress in the abdominal aorta of ApoE^{-/-} mice as animal model of vascular disease. Considering patients with congenital heart disease, Corsini *et al.* performed a quantitative patient-specific hemodynamic prediction of veno-venous collateral vessel occlusion for a patient who underwent a bi-directional Glenn procedure and compared predicted hemodynamics with post-operative measurements. Restrepo and colleagues developed a framework to assess the effects of geometric uncertainty in the surgical implementation of the Fontan connection on clinically relevant hemodynamic indexes. Kung *et al.* used computational techniques in Fontan patients to investigate the effect of several commonly observed dysfunctions (e.g., atrial-ventricular valve insufficiency) on exercise intolerance.

With regard to computational simulations of heart valve hemodynamics, structural and fluid–structure interactions analyses of mitral valves function and repair operations are reviewed and discussed by Chandran & Kim. Pan *et al.* investigated the influence of sinotubular junction and sinus diameters on aortic valve closure and blood regurgitation from the aorta into the left ventricle. Annerel *et al.* highlighted the role of valve orientation, size and the choice of realistic downstream geometry in the leaflet kinematics of an aortic bileaflet mechanical heart valve, using an image-based geometry of the aorta. Bicuspid aortic valve disease is investigated by van Ooij and colleagues, by applying computational techniques to derive wall shear stress *in vivo* from 4D flow magnetic resonance imaging. The flow through an artificial valve is then considered by Ezzeldin *et al.* as an application of a new multiscale strain-based model for shear-induced hemolysis. The effect of red blood cells on platelet transport is modeled by Mehrabadi *et al.*, focusing on arterial thrombus formation.

Contributions dealing with issues related to assumptions on boundary condition of hemodynamic models are given by Valen-Sendstad *et al.*, assessing how the estimation of inlet flow rates with diameter-based scaling laws is affected by the choice of the virtual inlet location in internal carotid aneurysms.

The potential of reduced order models in hemodynamic investigations is clearly depicted. In Perdikaris *et al.*, the problem of prescribing realistic conditions at boundaries for simulating blood flow in large arterial 1D networks is successfully faced by applying a fractal tree closure model. One-dimensional modelling is also featured in the contribution by Mynard & Smolich, who developed a comprehensive 1D model of the entire human circulation. A new open-source framework to model 0D vascular networks with pulse wave propagation models is introduced by Manini *et al.*

In this second part of the Special Issue on Computational Hemodynamics, 15 original research articles and one review article are presented. This collection of papers broadens the overview of the current research carried out by groups from all over the world given in the first Special Issue edited in January 2015, illustrating the vital role of computational hemodynamics in solving a large variety of problems and stimulating further interest and research.

To conclude, we are grateful to all authors who submitted their papers for publication in this Special Issue. We would also wish to acknowledge the numerous reviewers for their insightful and constructive comments, and the editorial staff of the *Annals of Biomedical Engineering* for their assistance throughout the development of the two Special Issues. Finally, we would like to thank the Editor in Chief for the enthusiastic support to this attempt of presenting directions where computational hemodynamics is making progress.

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