Preface

Cardiovascular diseases have a major impact in several countries and a widespread awareness exists that mathematical models and numerical simulations can help to better understand the physiological and pathological processes and their correlations. This book is addressed to graduate students and researchers in the field of life sciences, bioengineering, applied and numerical mathematics and medicine wishing to engage themselves in the challenging field of modeling physiological flows, with a special emphasis on cardiovascular flows.

The expertise required to a researcher wishing to work in this field is vast and multidisciplinary. This book, written by world recognized experts in the field, offers a sound and up-to-date state of the art of the development of mathematical models, numerical simulation codes, pre and post-processing tools.

The present volume is a natural continuation of the book "Cardiovascular Mathematics", MS&A series, published in 2009, and it contains selected invited papers of the Fourth International Symposium on Modeling of Physiological Flows, held in Chia Laguna, Sardinia, Italy on June 2–5, 2010 (http://www.mathcard.eu/mpf2010), sponsored by the European Research Council within the project Mathcard "Mathematical Modeling for the cardiovascular system" (ERC-2008-AdG-227058).

The first chapters provide a broad overview on the field, the focus then narrows on fluid and structural models, and heart electrophysiology. The complexity of the cardiovascular system calls for the integration of different models, operating at different levels of complexity and different spatial and temporal scales, and that can flexibly adapt to the need of the research at hand. Then, the last chapters address specific methodological contributions.

Chapter 1 critically reviews some of the common assumptions about the constitutive properties of blood flow and arterial walls, and their potential impact on the computed haemodynamics. Chapter 2 is devoted to the formulation of a simplified one-dimensional time-dependent non-linear mathematical model for blood flow in vessels with discontinuous material properties. Chapter 3 deals with blood flow components and their mutual interactions: in particular it illustrates the mathematical models for the formation and dissolution of blood clots known as hemostasis process. Chapter 4 presents a concise overview of various mathematical and numerical problems raised by the simulation of electrocardiograms (ECGs). A model for the propagation of the electrical activation in the heart and in the torso is proposed. A review of current mathematical and numerical models of the electrical activity in the ventricular myocardium is introduced in Chapter 5. The degenerate reaction-diffusion system called Bidomain model is introduced and interpreted as macroscopic averaging of a cellular model on a periodic assembling of myocytes. This model is coupled with an extracardiac medium and extracardiac potentials, computed from given cardiac sources in order to obtain body surface maps and electrograms. The focus of Chapter 6 is on the damage in the arterial wall model, in terms of experimental studies and computational applications. Structurally motivated multi-mechanism models, which explicitly fibre orientation as well as isotropic damage, are illustrated. A recently developed experimental system, which enables quantitative assessment of the microstructure simultaneous with mechanical loading experiments, is presented with application to the arterial wall, namely cerebral angioplasty. Chapter 7 recalls how experimental observations highlight the importance of altered haemodynamics on arterial function and adaptation. It contains a discussion of mechano-biological models for growth and remodeling of the arterial wall, by describing the intimate interaction between haemodynamics, cell activity, and wall mechanics. When the artery is described as a thin walled structure, and basic adaptations to perturbed pressure and flow, cerebral aneurysms, and vasospasms ca be successfully modelled treating the vascular wall as a membrane.

A general overview of the VPH/Physiome project developing multiscale tools and model databases for computational physiology is given in Chapter 8. Here the aim is to introduce the reader to the most important guidelines concepts in multiscale physiological simulations.

Chapter 9 addresses several phenomena bound to different time, constitutive and geometrical scales in the cardiovascular modeling. More specifically, the problem of integrating various geometrical scales is considered from a kinematical point of view, which amounts to integrate models with different kinematics, and in particular different dimensionality by making use of heterogeneous representations. Chapter 10 deals with the modeling of hematologic disorders associated with major changes in the shape and viscoelastic properties of red blood cells. Such changes can disrupt blood flow and even brain perfusion. A seamless multiscale approach is described, where blood cells and blood flow in the entire arterial tree are represented accurately using physiologically consistent parameters. A computational methodology based on dissipative particle dynamics which models red blood cells as well as whole blood in health and disease is illustrated.

Since degradable materials have found a wide variety of applications in the biomedical field ranging from sutures, local drug delivery, tissue engineering scaffolds, and endovascular stents. Chapter 11 introduces a bottom-up multiscale analysis applied to model the degradation mechanism which takes place in polymers matrices used in stents. The macroscale model is based on diffusion-reaction equations for hydrolytic polymer degradation and erosion, while the microscale model is based on atomistic simulations.

The development of new technologies for acquiring measures and images in order to investigate cardiovascular diseases raises new challenges in scientific computing. In fact, these data can be merged with the numerical simulations for improving the accuracy and reliability of the computational tools. Assimilation of measured data and numerical models is relatively new field in computational haemodynamics. Different approaches are possible for the mathematical setting of this problem. With this aim, Chapter 12 considers a variational approach, based on the minimization of the mismatch between data and numerical results by acting on a suitable set of control variables: in this way a mathematically sound (variational) assimilation of data can significantly improve the reliability of the numerical models, but also provide important features in view of the progressive adoption of numerical tools in medicine.

Finally, Chapter 13 describes efficient algorithms for generating high quality computational tetrahedral meshes for cardiovascular blood flow simulations starting from low quality triangulations, usually obtained from the segmentation of patient specific medical images.

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