Preface

In September 2014 we ran the sixth Summer School on Biomechanics that we have organized. This one, entitled "Biomechanics: Trends in Modeling and Simulation" was held at Graz University of Technology, Austria, and attended by about 90 Ph.D. students, postdoctoral researchers and university professors from more than 20 countries. We thought that it would be valuable to make the course material more generally available by publishing the lecture notes so as to provide an up-to-date account of some of the topics in the area. As things developed the material in this book in some cases has turned out to be somewhat different from the material that was presented in the Summer School, i.e., it has been updated significantly to account for subsequent developments. In addition, we have included a chapter on mixture theory which was not part of the Summer School. The subject of biomechanics is highly multidisciplinary and the content of the present volume ranges from multiscale continuum mechanics to computational modeling and applications to areas of clinical relevance such as myocardial infarction and vascular stenting.

The combination of modeling and computational methods provides the possibility to simulate multiscale coupled processes as a means to predict (patho)physiological functional interactions. This approach can, for example, provide information of academic, industrial, and clinical relevance that would otherwise not be possible. In the last few years modeling and simulation have significantly advanced our knowledge of the development of pathologies such as atherosclerosis, aneurysms, aortic dissections, and wound healing, and their prognosis. Simulations of clinical applications based on coupled models and powerful computational methods may lead to improved medical device implantations, diagnostics and treatment of tissue disorders, surgical planning and intervention.

This volume comprises seven state-of-the-art chapters on topics of modeling and simulation from the cellular to the tissue level. Chapter "Mixture Theory for Modeling Biological Tissues: Illustrations from Articular Cartilage" provides an introduction to mixture theory, and its application to articular cartilage with an emphasis on studies that provide validations of theoretical predictions. Particular attention is given to the theory governing biphasic mixtures consisting of a porous-permeable deformable solid matrix and an interstitial fluid. This chapter also contains a brief overview of the application of mixture theory to solute transport, reactive kinetics, and growth and remodeling. Chapter "A Bio-chemo-mechanical Model for Cell Contractility, Adhesion, Signaling, and Stress-Fiber Remodeling" focuses on a multi-field approach to modeling the mechanics of cell contractility, adhesion, signaling and stress-fiber remodeling, specifically involving biological, chemical, and mechanical interactions. Particular attention is given to the influence of different flat or patterned substrates or arrays of compliant posts on the contractile behavior of a cell, and the behavior is simulated using a finite element approach.

Chapter "Nonlinear Continuum Mechanics and Modeling the Elasticity of Soft Biological Tissues with a Focus on Artery Walls" provides a summary of the nonlinear theory of continuum mechanics required for the modeling of the elastic properties of soft biological tissues, with particular reference to the fiber structure of such tissues and the influence of residual stresses. The theory is applied to a prototype problem of the extension and inflation of a fiber-reinforced thick-walled cylindrical tube taking account of fiber dispersion and residual stresses. Chapter "Microstructure and Mechanics of Human Aortas in Health and Disease" summarizes recent developments aimed at characterizing the microstructure and mechanics of human aortic tissues and also of tissues subject to diseases such as aneurysms and aortic dissection. In particular, a general fiber dispersion model is reviewed and used to capture the differences that have been identified in the microstructure and mechanics of healthy and aneurysmatic aortas. Modeling and simulation of an aortic dissection is provided using the novel phase-field approach. Finally, an aortic clamping simulation is provided for illustration including inelastic phenomena such as stress softening and permanent deformation. Chapter "Arterial and Atherosclerotic Plaque Biomechanics with Application to Stent Angioplasty Modeling" focuses on the biomechanics of atherosclerotic plaques based on the constitutive theory of tissue anisotropy, remodeling and constitutive damage modeling, including material characterization based on experimental data. Application of the theory is illustrated in the computational simulation of the deployment of a stent during an angioplasty procedure. The main challenges for the future in characterizing the complex atherosclerotic tissue and its modeling are identified.

Chapter "Biomechanics of Myocardial Ischemia and Infarction" is concerned with the biomechanics of heart disease, in particular myocardial ischemia and infarction. The structure and the mechanical properties of a normal heart are reviewed followed by a discussion of the structure and the mechanical properties of a scar produced by myocardial infarction and its healing post infarction. Analytical and computational models that provide insight into the functional consequences of myocardial infarction are discussed along with potential therapies. Finally, there is discussion of emerging models of wound healing and growth and remodeling in the myocardium. The final chapter discusses a network approach to modeling the fiber structure in tissues, with particular reference to translating the microscopic behavior to a macroscopic finite element scheme for networks of macromolecular fibers such as collagen. This chapter provides a basic theoretical framework for studying networks with reference to the computational demands in scaling up from the microscopic to the macroscopic level.

We hope that this volume will be useful not only for those who work in the areas of biomechanics and mechanobiology highlighted above but also for those in other areas such as biomedical engineering, biophysics, mechanical and civil engineering, applied mathematics, physiology, and materials science, who might wish to contribute to this developing subject and tackle some of the challenges it faces. Multiscale approaches and multidisciplinary studies bring together scientists with expertise in novel multiscale modeling, computational analysis, and sophisticated experimentation to determine the influence of the interactions of the structures, biology, chemistry, and mechanics at the different scales. Continuing significant advances in experimental techniques, including imaging, computational methods and computer power and multiscale modeling make this a dynamic and rapidly developing subject which offers many challenges for the future. The contents of this book provide a platform for further developments in this exciting subject.

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Graz, Austria/Trondheim, Norway — Gerhard A. Holzapfel
Glasgow, UK — Ray W. Ogden
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