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# Computational Biomechanics for Patient-Specific Applications

Biomechanics as a scientific discipline is over 100 years old. *Computational* Biomechanics, which invokes methods of mathematical modelling and computer simulation to address sophisticated problems is of course much younger, but nevertheless has been around for about 40 years. However it is only quite recently, that a paradigm shift towards modelling and computer simulation of individual patients has begun.

It is now widely recognized that translating the extraordinary success of computational science in general, and computational mechanics in particular, to fields outside traditional engineering, especially biology and medicine, is the great challenge facing researchers; and represents the next frontier to be conquered.

The quickly growing scientific community of computational biomechanists creates models that are tailored to individual patients. These models can be used to augment the clinicians' ability to effectively integrate and act upon the wealth of data available to them from modern diagnostic (especially imaging) devices. Our goal is to create an integrated, patient-specific representation that can become a critical part of the overall understanding of each patient and each treatment decision.

My vision, shared with many colleagues in our research community, is to enable a surgeon to simulate a procedure within the operating theatre, in real time, using readily-available computing facilities and to visualize the results immediately. Thus, a surgeon would be able to assess the implications of each stage of the procedure, explore possible alternative courses of action, or solutions to problems that arise as events unfold during a complex operation. Achieving this goal requires the creation of an easily-manipulated computational grid, which would allow the user to intuitively zoom-in or out of regions of interest. Robust, accurate and extremely fast solution methods for the fundamental equations which describe the biomechanical behavior of the subject are also essential. The key requirement is that the user—ultimately a surgeon—need not require specialist knowledge in the field of numerical computation. Hence, the operation of such a system must be fast and reliable, and the results presented to the surgeon must be within guaranteed bounds of accuracy.

The significance and impact of this research program for the practice of medicine can only be compared to the enormous influence of the introduction of computational mechanics-based computer-aided design and manufacturing (CAD/CAM) systems in traditional engineering. It is my strong belief that in the near future Computer Integrated Surgery (CIS) systems will become an integral part of the clinical tool set, enabling an exciting new era of personalized medicine based on patient-specific scientific computation.

This Special Issue on Computational Biomechanics for Patient-Specific Applications contains twenty papers selected to be representative of the principal application areas, as well as the geographical spread of the contributors.

I have attempted to include a balance of authoritative reviews and original research papers. The first three contributions are devoted to the often underestimated problem of patient-specific model generation. In my opinion, segmentation and meshing are the backbone of most patient-specific computational simulations, yet rarely receive the attention they deserve. Many studies assume that this part of the workflow is trivial and repeatable. I do not believe this is the case. Importantly, for the practical implementation of biomechanical computations in a clinical environment, segmentations and computational grids (e.g., finite element meshes) must be rapidly and automatically obtained from standard diagnostic images. The resulting meshes must be flexible, adaptive and straightforward to manipulate by a non-specialist, i.e., the surgeon. The current practice of computational model generation involves many formidable steps that are very difficult to automate. Therefore entirely novel approaches are needed.

The ensuing six contributions are in the area of cardiovascular biomechanics. Judging by the number of research groups active in this area, it appears to be the second largest field of interest within computational biomechanics, after musculoskeletal biomechanics. Cardiovascular biomechanics is unique in that it requires multidisciplinary approach to probably the greatest extent, invoking the integration of solid mechanics, fluid mechanics, electromagnetism and physiology, at scales ranging from the organ to the cell.

The subsequent six papers are in the area of soft tissue biomechanics, applied to the brain, liver, the soft tissues of the pelvic floor, and breast. The immense complexity of problems in this field arises from the very large deformations of tissues and the difficulties of identifying suitable boundary conditions for the models.

Finally we include five papers from the field of musculoskeletal biomechanics, the oldest and most mature area of investigation. Personalized treatment methods, such as custom-made implants, are becoming the norm in this area, but patient-specific biomechanical analysis of accidents leading to personalized trauma management plans is in its infancy.

I would like to sincerely thank the Editor-in-Chief, Professor Kyriacos A. Athanasiou, and the members of the Board of Associate Editors of the Annals of Biomedical Engineering for inviting me to compile this Special Issue. Sincere thanks go to the Journal Editorial Manager Dr. Holly Ober who has skillfully guided me through the editorial processes. Over one hundred reviewers have helped to evaluate submissions and they have substantially contributed to the quality of this Special Issue.

Thank you to all the authors, from four continents, for submitting your work to this Special Issue and our most sincere apologies to those groups whose very good papers we were unable to include.

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