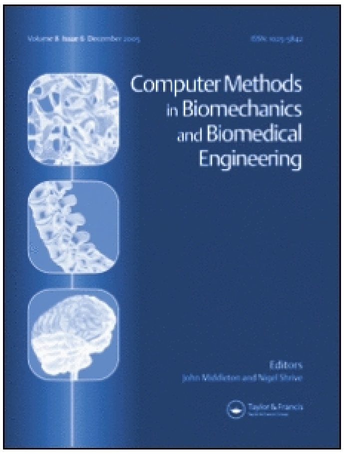

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Special issue on computer simulations of mechanobiology

Ellen Kuhl [a]
[a] Departments of Mechanical Engineering and Bioengineering, Stanford University, Palo Alto, CA, USA

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PREFACE

Special issue on computer simulations of mechanobiology

Guest editor: Ellen Kuhl

Departments of Mechanical Engineering and Bioengineering, Stanford University, Palo Alto, CA, USA

One of today's most challenging applications of computational modelling is certainly the area of biomechanics, a widely recognised, rapidly growing but not yet clearly defined field that is undoubtedly a multi-disciplinary science par excellence. In contrast to traditional engineering materials, *living* organisms show the remarkable ability to adapt not only their function, but also their material properties, their internal architecture and their entire external structure to environmental changes. Biomechanics thus provides a tremendous selection of new and fascinating areas of application such as the functional adaptation of hard tissues such as bone, teeth, or vertebrae, fracture and healing of bones, mechanically-induced growth and remodelling in arteries, the adaptive response to graft implantation or stenting of vascular tissues, in-stent restenosis, ventricular remodelling, the simulation of actively contracting skeletal or cardiac muscle and loss and restoration of function in damaged or diseased tissue, to name but a few.

Since hard tissues typically undergo small deformations and behave nearly elastically in the range of interest, the first rigorous mathematical models for biological tissues that were introduced in the mid-1970s mainly addressed hard tissues such as bone. It was only in the mid-1990s, that rigorous geometrically non-linear approaches for soft tissues were introduced. These kinematically non-linear models were also capable of addressing issues of pre-stress, a typical characteristic of soft tissues. Since then, more sophisticated models have been developed to capture effects such as anisotropy, viscosity, damage, or plasticity. Despite these tremendous developments, biomechanics today is still in its infancy and it would certainly be too ambitious to claim that our current models explain every detail of each individual medical process. Rather, the goal is to develop models that capture the essence of mechanical and biological interactions allowing their outcome to be more precisely understood.

Ultimately, the improved understanding of how hard and soft tissues react in response to changes in mechanical loading will enable the targeted manipulation of tissue adaptation and allow the design of a whole new generation of clinical therapies. A crucial step towards this goal, however, is the understanding of mechanotransduction within the tissue: How do cells sense load? How are signals transmitted within the cell? How do individual cells communicate with one another? Recent advances in this field indicate that multi-scale multi-physics simulations provide a promising means to explore mechanotransduction on the cellular scale and carry the information all the way up to a macroscopic tissue or even organ scale. While small scale analyses can provide new insight into the fundamental mechanisms and help to explain signalling pathways, large scale analyses are essential to successfully address clinically relevant issues to improve quality of life and longevity.

Simulations can help to provide further insight into complex biomechanical phenomena and capture basic dependencies and trends. The finite element method that was introduced in the late 1950s by aerospace engineers provides a powerful tool that allows us to account not only for complex arbitrary geometries but also for non-linear phenomena and multiple interacting fields. The first application of the finite element method to biomechanical problems dates back to the beginning of the 1980s. It was driven by orthopaedic applications in hard tissue mechanics. Since the mid-1990s, finite element research has been dominated by multi-physics simulations that require increasingly sophisticated mathematical techniques.

In this respect, the field of tissue engineering, which aims at creating living artificial tissue substitutes with human cells, can certainly be identified as one of the most promising applications of biomechanics in the future. Another exciting future application is the area of optimised patient-specific medical care. In modern biomechanics research, a strong trend away from diagnostic empirical disease-based medicine towards predictive medicine with the help of reliable computational simulations is in evidence. Based on the development of modern computer technologies in combination with novel diagnostic imaging techniques, we might one day be able to simulate each patient individually, maybe even in real time and provide immediate guidelines for improved individual medical treatment.

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In this special volume, research groups of 12 leading experts in computational biomechanics share their views on the current state of knowledge in modelling and mechanobiology. Five contributions address hard tissue such as bone and vertebrae, seven contributions focus on soft tissue such as skeletal muscle and vascular tissue. Half of the contributions are conceptual in nature with a key focus on the development of novel modelling and simulation techniques, while the other half combines both experimental and computational techniques. Some manuscripts address purely mechanical effects such as damage and fracture, whereas others discuss the coupled biomechanical phenomena of growth and remodelling. Remarkably, in one way or another, all contributions investigate, simulate, or model the *living nature* of biological tissue which is one of the most challenging and exciting characteristics to explore, to understand, and to potentially tune for novel clinical applications in the twenty-first century. Enjoy this unique collection of different perspectives on pioneering computational modelling techniques for state of the art biomechanical phenomena.

Contributions to the special issue