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Multiscale/multifield experiments and modelling in biomechanics – from the single cells to the whole organs

Abstract

One of the most outstanding properties of biological tissue is that it has highly complex microstructures that enable organs to perform the most complex functions. In contrast to engineering materials, e.g., biological tissue exhibits other fields in addition to the mechanical field, such as hormonal, electrical or chemical fields, which cause the tissue to exhibit both passive and active contraction properties and result in the living tissue continuously renewing and changing itself. These properties, outlined only roughly and not completely, lead to great challenges in the experimental investigation but also in the modelling of such tissue properties.

In this talk, different biological tissues are presented that fulfil the criteria described above. Skeletal muscles are a particular example. Skeletal muscle tissues are composed of interconnected contractile and structural proteins, membranes and other extracellular matrix (ECM) components that enable active and passive force transmission. To better understand the functions of healthy and diseased muscles, a better understanding of their individual structural components (e.g. myofibrils, muscle fibres, muscle fibre bundles and ECMs) is required. In recent decades, it has been confirmed that muscles are essentially controlled by their micro- and nanoscale structures. In short, skeletal muscle tissue has a three-dimensional and highly hierarchical architecture in which muscle fibres and the ECM interact to generate active forces and resist external loads. While the muscle fibres generate active forces during contraction, the ECM acts as a connective tissue that links the muscle components and transmits loads over multiple size scales. Skeletal muscle tissue is characterised by varying degrees of complexity and exhibits partly isotropic and strongly anisotropic mechanical properties.

Computational multiscale modelling of skeletal muscle tissue can help to understand the processes that take place during active and passive loading, and is particularly challenging due to the composition, complex spatial distribution and orientation of its components and their respective internal hierarchical structure, which together contribute to the overall movement, force generation and gait stabilisation properties of skeletal muscle. On the other hand, the multiscale experiments required for such a model are also a major challenge, especially at the micro level.

In this talk, multiscale experiments at the micro and macro level will be presented. At the micro level, the mechanical properties of muscle fibres and the ECM are characterised. Different deformation states will be presented and discussed. At the macro level, experimental investigations at the tissue and organ level are presented. By investigating the different scales, it is possible to view and better understand phenomena such as tension-compression asymmetry (TCA) in the light of the different scales.

The data generated from the experimental investigations provide valuable information for the identification of model parameters as well as for the validation of a corresponding muscle scale model.

CV

Prof. Dr.-Ing. Markus Böl received his diploma in civil engineering from the Technical University of Dortmund and his doctorate from the Ruhr University of Bochum in 2005. From 2009-2020, he was Professor of Solid Mechanics at the Technical University of Braunschweig. Since 2020, he has been Head of the Institute of Mechanics and Adaptronics at the Technical University of Braunschweig. Markus Böl can look back on various international research stays at Stanford University and Graz University of Technology. From 2017-2019 he was council chairman of the graduate academy GradTUBS and since 2017 he is board member of the research center “Center for Mechanics, Uncertainty and Simulation in ENgineering - (MUSEN)” at the Technical University of Braunschweig. Since 2015 Markus Böl is member of the faculty council of the faculty of mechanical engineering and became in 2023 dean of the faculty of mechanical engineering. His research focuses on (numerical) multiscale/multifield material modelling. In addition to traditional materials, he also deals with advanced materials such as biofilms, skeletal muscles or smooth muscles, to name but a few.