BIO-POROMECHANICS. PROBLEMS OF MODELLING
TISSUES AND BIOMATERIALS

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1. Motivation

Most biological (natural) materials and biomaterials (engineered materials replacing functions of tissues or organs) in their natural or working environment consist of solid skeleton filled with fluid. In case of tissues the skeleton is a complex hierarchical structure comprised of cells, vascular systems, mineral phase, etc (see e.g. [1]). The fluid in pore - extra cellular space is a composition of constituents plying different structural and biological roles within organisms. Biomaterials have usually less complex constitution and structure and as the result can realize less functions than biological materials, see Fig. 1.
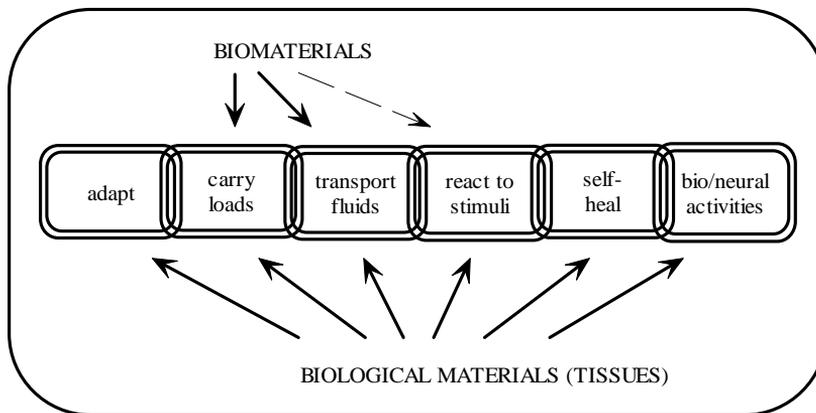

Fig. 1. Diagram showing functions of biomaterials and biological materials

The internal complexity of the materials of interest and range of phenomena and functions which are to be covered must determine useful modelling tools.

2. Poromechanics – a tool for modelling biological materials and biomaterials

Poromechanics is the coupled mechanical model of saturated porous materials which incorporates basic interactions between porous skeleton and pore fluid, including volumetric couplings, viscous and inertial interface forces. More advanced approaches try to include in the model characteristics of internal structure and information on properties of phases. Since its origin in the mature shape (the foundations of poromechanics were laid by M. A. Biot, see [2], [3], [4]) it has found number of successful applications for modelling rocks, soils, sound absorbing materials but also tissues (e.g. bones, musceles, cartilage, brain) and biomaterials (e. g. scaffolds, hydrogels). Among others the model was useful to predict division between phases of dynamically applied stress to bones and muscles followed by further redistribution of stress in time; It describes basic

properties of waves in bones and soft gels; It explains the evolution of deformation and porosity in diseased or injured brain. Despite that however there is a growing awareness that notions and equations of classical poromechanics when applied for modelling biological materials or biomaterials must be frequently supplemented with some components resulting from the particular material properties and functions.

From the mechanical point of view the material properties which cause the peculiarities of modeling tissues and biomaterials are: high porosity, anisotropy of mechanical and structural parameters, micro- and macro-inhomogeneity, complexity of interfacial conditions etc. They generate theoretical difficulties to find proper constitutive equations, boundary conditions and finally make credible simulations without known benchmark solutions. However, the least solved problems seem to be that which are related to elaboration of reliable experimental techniques which can determine numerous model parameters from tests made for usually small, inhomogeneous and anisotropic samples of materials. The problem is yet more striking when one realizes that material parameters determined in vivo, in situ (death tissue in its environment) and in vitro (death tissue removed from its environment) could be significantly different.

3. Discussion of applications

We will discuss some of the above problems as related to applications of poromechanics in modelling:

1) wave propagation through trabecular bones,
2) transport and deformation in brain, and
3) coupled chemo-mechanical behaviour of reactive gels.

In all the above cases the analysis will concentrate on proving high capability of poromechanics to describe phenomena which are specific for biological materials or biomaterials and also show limitations and unsolved topics within the approach. Connections of the modelling with predictive description, diagnostic applications as well as design of biomaterials will be highlighted. The discussion will be based on original results (see e.g. [5], [6]) and review of current literature and will be illustrated by simulations and results from experiments.

4. References

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