MODELING THE REACTION OF A LIVING CELL CYTOSKELETON TO MECHANICAL STRESS IN A FLOWING LIQUID

Natalia Branecka (1), Marek Pawlikowski (1)

(1) Warsaw University of Technology, Poland

Introduction

Studies on biomechanics of living cells are important in predicting their behavior in living tissue in response to naturally occurring mechanical stimuli. By recreating the types of stress [1,2] that a given type of cells experiences in the natural microenvironment and by examining their reactions, it is possible to model the behavior of both cells and entire tissues in the body.

The mechanical properties of cells are primarily influenced by the cytoskeleton, which acts as a scaffolding on which the cell is based, and which reacts to changes in the physical environment in real time [3,4]. Assuming this, to adequately describe the behavior of a cell, it is necessary to describe the impact of mechanical loads on the architecture of the cytoskeleton and its influence on the changing properties of cells [1].

Particular attention should be paid to the cells of the bone tissue, which is subject to the constant influence of mechanical stresses [3,5]. By studying how cells respond to mechanical stress, one can predict what conditions will cause them to die and which conditions will increase their metabolic activity. This knowledge is extremely important in prosthetics and in the treatment of bone diseases.

Methods

The aim of the work is to develop an analytical model and to conduct numerical simulations using the finite element method in COMSOL, which describe the reactions of single, living connective tissue cells in response to mechanical loads.

The secondary aim of the research is to develop a numerical model describing the transformation of the cytoskeleton architecture, especially actin filaments [6] under the influence of mechanical loads and to link the change in this structure with the mechanical and rheological properties of the cell. The dominant research hypothesis is the assumption that the changes in the architecture of the cytoskeleton can be described by optimizing equations, assuming that its reconstruction is aimed at maintaining unchanged internal conditions, homeostasis, at the lowest energy cost formulated as equation 1.

$$W = \frac{1}{2}\sum_i^2 \sum_j^2 \sigma_{ij}\epsilon_{ij} \quad (1)$$

The proposed model considers the time-dependent and external loads dependent, and consequently also internal loads dependent, properties of the components of the cytoskeleton. This means that the constitutive equations depend on the current state, the coefficients adapt to the state at a given moment in time.

To make the developed model adequate to the actual cell behavior, it was necessary to constantly verify the calculations with the experimental reality and selecting the correct initial parameters for the models.

Results

The simulations and experiments confirmed that it is possible to approach the cytoskeleton modeling using the optimization method. The compaction lines determined by this method coincide with the cytoskeleton thread architecture under the influence of external loads changing over time, as shown on fig.1.

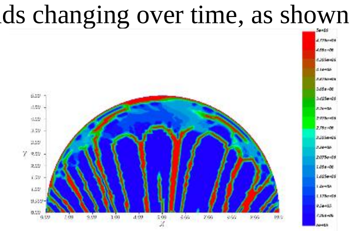

Figure 1: Cell loaded with homogeneous pressure and flow.

Further and more in-depth experimental verification is still needed, but the direction of research seems promising.

Discussion

The main goal of this work was to develop an analytical model based on optimization equations that adequately describes the cytoskeleton adaptation to the external loads. The presented numerical simulations confirmed that the formulated mathematical description makes it possible to determine changes in cytoskeleton architecture, taking into account the strain energy density. This makes it possible to compare the proposed model to the models already developed, first of all tensegrity model.

References

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