A PRELIMINARY 3D FINITE ELEMENT STUDY OF CELL-SUBSTRATE INTERACTION IN MICROGRAVITY CONDITIONS

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Introduction

It is well stated that microgravity affects cell behavior. Cells critically depend on the mechanical properties of their environment. The substrate elasticity is recognized to play a significant role in cellular processes as adhesion and differentiation [1]. Several studies have investigated the cells response to substrate. However, these works were established in gravity conditions. Available studies in literature addressing the cell-substrate interactions in conditions of microgravity are extremely limited [2]. In this study, we propose a finite element (FE) model to analyze the mechanical response of a substrate due to cells presence, in conditions of microgravity.

Methods

A 3D FE model has been developed to predict the mechanical response of a substrate induced by a group of cells. The geometrical model simulates idealized cells, composed of nucleus, cytoskeleton and cortical shell, seeded on a gel substrate that is placed on a rigid glass. Dimensions of cells and substrate are in accordance with [1]. The geometry is then converted into a non-uniform tetrahedral mesh with roughly 350k elements and 1500k degrees of freedom. The cell components and the substrate gel are modelled with hyperelastic Neo-Hookean materials. Different values of Young's modulus are considered for the cell (E_{cell}), i.e. 1 kPa, 12 kPa, 34 kPa mimicking mesenchymal stem cells (MSC), myoblasts and osteoblasts, respectively [1]. A Poisson's ratio of 0.45 is set for cell components and substrate. For each value of E_{cell}, we performed FE simulations with different substrate stiffness spanning from 1 kPa to 40 kPa. A uniform prestress as in [1] is considered throughout the entire cytoplasm. We perform all simulations considering microgravity conditions equal to 10^{-6} g.

Results

We investigate the interaction between cells and substrate in terms of gel displacement and maximum principal logarithmic strain. Displacement (Figure 1) is maximum on cell edge and decreases inside and outside the cell. In this configuration, reduced gel displacement is observed between a cell and its neighbors, suggesting a weak crosstalk [1]. Figure 2 compares the behavior of different cell types in function of substrate stiffness. For MSC and myoblast, the strain decreases with increasing gel stiffness, while osteoblasts are insensitive to gel stiffness.

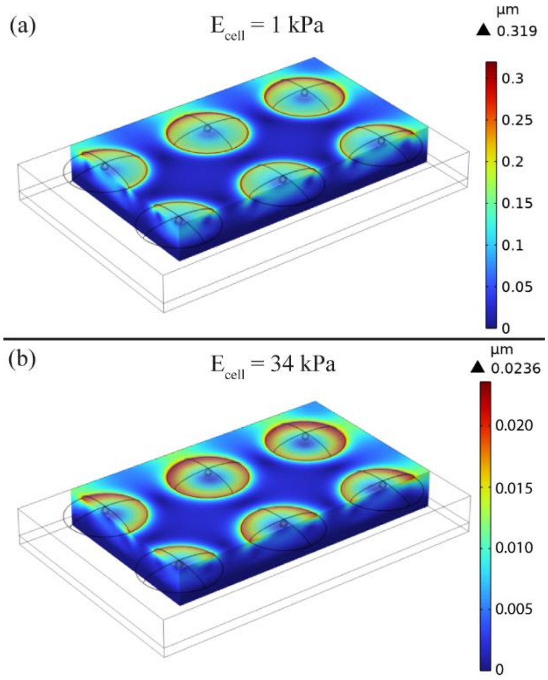

Figure 1: Displacement of a soft substrate (E=1 kPa) induced by cells with (a) 1kPa and (b) 34 kPa stiffness.

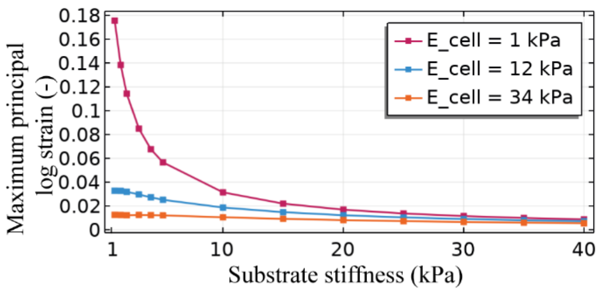

Figure 2: First principal logarithmic strain represented for different substrate stiffness for various cell types.

Discussion

The FE model predicts that also under microgravity, subtle changes in gel stiffness will significantly interact with MSC. The model may contribute to optimize the design of biomaterials for cell cultures during space flight. Tissue engineering in microgravity is a key research area that can be beneficial to understand crucial mechanisms in human health and disease.

References

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