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A Study of Cancer Cell Mechanics Using 3D Finite Element Modelling

Abstract

Using finite element modelling, a robust computer model of a cancer cell is shown. The model accurately reflects the nuances of the numerous cellular substructure components. The impact of cytoskeleton deterioration on the cancer cell's overall elastic characteristics is discussed. The fact that many anti-cancer medications disrupt the intrinsic mechanics of the cytoskeleton as therapeutic therapies for the eradication of cancer tumours is the motivation for deteriorated cancer cellular substructure, the cytoskeleton. The cytoskeleton (CSK) is a cell's most important mechanical component. Furthermore, parameter investigations revealed that the material properties of the continuum (thickness and elasticity) have a substantial influence on the overall cellular stiffness, but Poisson's ratio has a lesser influence. The proposed FEM models may be used to quantify the contribution of main cell components to overall cellular stiffness, as well as to gain insight into how cells respond to external mechanical stimuli and explore the underlying mechanical mechanisms and cell biomechanics.

Keywords: FEM model, Cytoskeleton, 3-D model.

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Introduction

While it is commonly acknowledged that cancer cells' hemodynamic transport through the microcirculation plays a critical role in the disease's genesis, the impact of cell structure and biomechanics on cell trajectory and dissemination locales is poorly understood. Our understanding of how changes in cell characteristics, which vary by cancer type, emerge at scale and influence metastatic attachment preference in the vascular tree is limited. We need to determine which components of the cell must be included in the model and how to tweak their settings to fit certain cancer kinds in order to develop a cell-specific model that is robust and adaptive to represent different cancer types throughout a range of conditions [1]. In terms of cell mechanics, deformability is a key feature of cancer cells that influences microcirculatory transport behaviour, and this property is known to differ by cancer type. To date, researchers have developed a number of approaches ranging in complexity to accurately model aspects such as cell deformability. Membrane model based approaches, in which a membrane encloses a viscous fluid and generally consists of either single-membrane or nucleated cell models are popular among these methods. The outer membrane and nucleus are modelled as two independent membranes in these cells, which are also known as compound

cells. The membrane stiffness is used to govern deformability in such techniques, and the precedent of employing these models in a more generic way to supplement experimental observations has been established during the last few decades. The liquid drop technique with membrane surface tension has been used to model single membranes as well as complex cells, with many of them being used to interpret mechanical properties of cells from experimental data [2]. More comprehensive membrane models that contain elasticity and other complications have been constructed and confirmed against tests. Researchers created a two-dimensional compound cancer cell model with elastic membranes that could represent cell-cell adhesion and cell multiplication. They used a 3D single-membrane model to simulate cancer cells with membranes modelled by non-linear elastic bead-spring networks to aid in their experimental study of cancer cells and clusters squeezing through capillaries, 2D single-membrane model with interconnected Kelvin-Voight elements, and observed good agreement with experiments. The computational efficiency of membrane-model based techniques is a significant advantage for large-scale simulations that resolve cell interactions and fluid flow in complicated 3D vasculatures. In silico frameworks for 3D microcirculatory flow simulation, which has been a strong area of research for the past decade, such approaches have been combined. The immersed boundary

approach (IBM) has been a popular choice among the several methods developed due to its computing efficiency in accurately simulating complex 3D flows. Separate solvers for fluid mechanics and solid mechanics are two-way connected with the IBM [3]. To solve the governing flow equations, numerical methods like the lattice Boltzmann method (LBM) or the finite volume method (FVM) are commonly used, and methods like the finite element method (FEM) are used to determine the stresses generated in cell membranes as they deform in response to the fluid flow. The Skalak constitutive law is a popular choice for describing the stress-strain relationship in deformable cells. While this equation was created to represent red blood cells (RBCs), it has also been used to represent generic cancer cells by just assuming that they are spherical when undamaged, bigger, and stiffer. This concept has also been used to various membrane models and in silico methods. The Skalak model is useful for simulating cancer cells since it is a strain-hardening model, and filamentous actin, which is a major contributor to deformation resistance, is known to exhibit strain-hardening behaviour.

Conclusion

While generic cell models have provided wide insights into cell transport behaviour, no standard approach for adapting

such computational models to a specific cancer cell type has been devised. Furthermore, there are few systematic studies comparing cell models with various components to best fit experimental data under a variety of situations. For determining cell attributes, a variety of instruments have been developed that look at behaviour in both flowing and static/ quasi-static environments. Given the complicated structure of cancer cells and the possibility of rate-based property dependence, determining the quality of a model by comparing it to observe behaviour from both of these viewpoints is critical for correctly identifying model components required to reflect observed behaviour.

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