CYTOSKELETON DYNAMICAL BEHAVIOR APPROACHED BY A GRANULAR TENSEGRITY MODEL

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INTRODUCTION

The mechanical behavior of cells plays a fundamental role in the tissue development and adaptation. Adherent cells are supported by their cytoskeleton (CSK), an internal pre-stressed framework composed of numerous interconnected filaments. For instance, contractile actin filaments (AF) generate tension forces toward the whole cell, especially in the basal side to strengthen the cell attachment to the extracellular matrix. This internal tension is balanced by microtubules (MT) associated to intermediate filaments (IF) that appear to resist to compression. By polymerization or depolymerization of AF and MT, the CSK continuously reorganizes itself according to the external mechanical microenvironment. Classical models based on tensegrity concept are consistent with biological observations of mechanical behavior of adherent cells such as strain-hardening, prestress-induced stiffening, viscoelastic properties [2,3] nonetheless the fixed connectivity between their constitutive elements (cables and struts) limits the description of the CSK reorganization. The aim of the present study is to develop a mechanical model based on divided medium theory to estimate the dynamical behavior of the CSK pre-stressed structure.

METHODS

To describe the CSK of an adherent cell, our 2D model is composed of numerous rigid disks arranged in a compact configuration whose shape is a 80 µm-diameter half disk and whose basal side is stuck on a flat substrate. Among these disks a larger one represents the nucleus (Figure 1). Within this assembly of elements in cohesive contact are distinguished several collections of elements on which particular interaction laws are applied. To represent the cell adhesion some disks of basal side interact with the substrate according to a highly cohesive contact law. To characterize the stress fibers that generate internal tension toward the whole cell a network of at-a-distance interactions of elastic tension are defined between some disks of the model boundary and especially between disks of the basal side that adhere to the substrate. The large disk that represents the nucleus interacts in the same way with those singular bodies. At-a-distance elastic tensions are also defined between disks of the apical side of the model to represent the cortical actin network located under the cell membrane. The model is then submitted to uniaxial compression at 3.10^{-3} m/s for a final deformation of 30%. The mechanical equations are resolved using a numerical method of non-smooth contact dynamics [3].

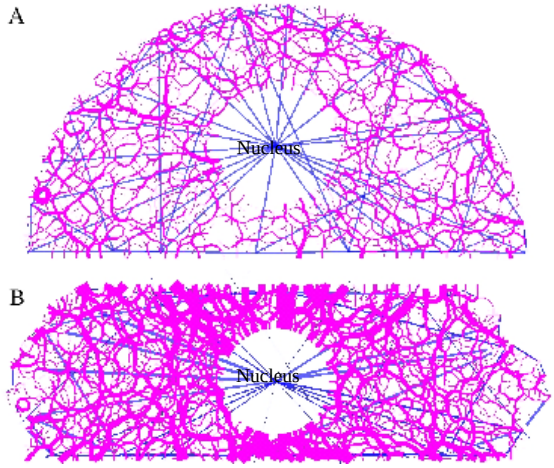

Figure 1: Distribution of forces within the granular tensegrity model. (A) at reference state (before loading) and (B) at 30%-compressed state. The blue straight lines represent at-a-distance forces of tension and the purple diffused lattice shows the network of compression forces.

RESULTS AND DISCUSSION

The first results obtained by the 2D granular tensegrity model show the internal force distribution (Figure 1). To balance the at-a-distance or cohesion tension forces, some elements in contact form chains of compression and thus a compression network inside the whole structure. Under compressive loading, elements rearrange themselves modifying their connectivity and the magnitude of interactions to balance the external applied force. Some at-a-distance elastic tensions vanish, new ones appear. Considering the prestretched actin network in analogy with the tension distribution and the MT associated to the IF network in analogy with the compression distribution, the 2D granular tensegrity model shows the organization of the CSK filaments and its variation under external applied stress and thus should provide a useful approach for investigating how each of the CSK substructures may be involved in the mechanical response of living cells.

REFERENCES

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