Cell-centred model for the simulation of curved cellular monolayers

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ABSTRACT

Recently, it has become apparent that mechanical stimuli have a key role in governing the dynamics of multicellular systems, and that the stress state of the cell and its neighbourhood is responsible for cell shape changes during cell migration [1], embryo development [2] or organogenesis [3].

Due to the reasons stated above, we propose a computational model that is able to simulate global embrygenetic cell shape changes in phenomena such as invagination and germ-band extension, which are accompanied by cell reorganization and cytoskeleton remodelling. We resort to the cell-centred model of the tissues, where cells are represented by their centres, and their mechanical interaction is modelled through active non-linear elastic laws with a dynamically changing resting length. Cell-cell connectivity, which defines also cell-cell neighbourhood, is computed by incorporating a modified Delaunay triangulation, in combination with a mapping technique in order to obtain triangulation on curved manifolds. To obtain cell boundaries, Voronoi tessellation of the Delaunay triangulation is obtained.

The elastic response of the material is defined by a scalar potential associated to each connecting bar element between a pair of cell centres, i.e. the mechanical state of the material is only provided by the cell centres position disregarding membrane forces. As a result, mechanical equilibrium within the whole material is provided by balancing the forces at each node, exerted by its neighbours via connecting bar elements holding the applied rheological properties.

Our numerical results show that even a linear elastic cell-cell interaction model may induce a global non-linear response due to the reorganization of the cell-cell connectivities [4]. To mimic the global visco-elastic response of the tissues, this plastic-like behaviour is combined with a non-linear rheological law where the resting length depends on the elastic strain. The model is applied to simulate the elongation of planar and curved monolayers (see Fig. 1).

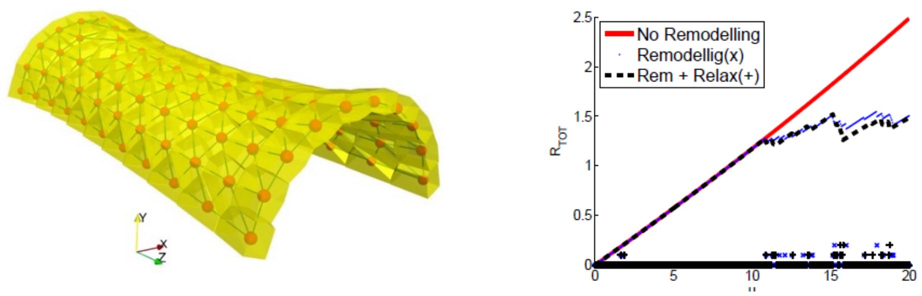

Figure 1: Left: Deformed curved monolayer when subjected to imposed stretching. Cell centers (red), cell-cell connectivity (green, Delaunay triangulation) and Voronoi tessellation (yellow) are indicated. Right: displacement-reaction curve when no remodeling is allowed and when it is, without stress relaxation and with it (Rem + Relax). Symbols (x) and (+) indicate number of connectivity changes on the tissue.

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