Physically-based 3D simulations of cellular traction forces, migration and deformation of cells adherent to a substratum

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Abstract: A suggestive approach of the cell mechanical activity can be based on simulation models considering the contractile activity of the cell cytoskeleton on one hand, the dynamic formation and breakage of cell attachments with the underlying substratum on the other hand.

We have developed a physically-based interactive 3D computer model which integrates a mechanical analysis of: - the cell spreading and contraction, - the resistance of and affinity of cell-substratum adhesiveness. In our model, each structure is a part of a global object. Each part of the global object is described by a set of mass points on its contour and defined locally in terms of physical (mass, velocity) and mechanical parameters (compressibility, elasticity/rigidity).

Our approach consists in uncoupling normal finite forces and constraint forces. Our method considers all kind of differentiable constraints (volume constraints, fixed or moving position constraints, …). Particularly, the volume can be kept exactly constant during deformation without using an iterative process (as used in Lagrangian approaches).

A limited number of forces is used to deform the object, the most interesting being contraction forces (modelling the cell contractile activity) shape memory forces (rendering elastic behaviour). All these forces are computed by using the attractive point concept: at each iteration, the ideal position (or speed) for a given mass point is first computed, then a spring force is modelled between the real position and the ideal position (which becomes an attractive point). Some simulation results illustrate the interest of our approach for analysing different aspect of cell deformation and locomotion)

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