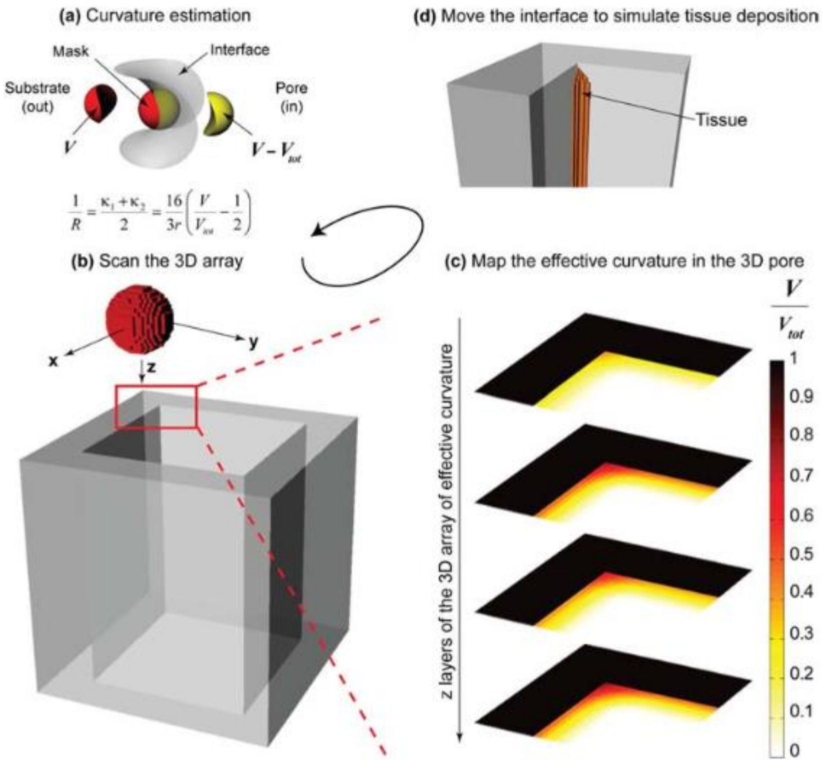
A three-dimensional model for tissue deposition on complex surfaces

Abstract

Biological processes are controlled by the biochemical composition and the physical properties of the environment. For example, geometrical features have been shown to influence cellular, multicellular and tissue behaviour. Moreover, the properties of these soft living materials affect their surface tension and thus, their shape. Two-dimensional (2D) models of geometry-driven growth suggest this interplay as responsible for the excellent control of tissue patterning throughout life. In this study, a digital 2D model of curvature-driven growth applicable to images from tissue culture experiments is extended to three dimensions. Artificial geometries were used to test the relevance and the precision of the simulations. The implementation of cell migration was also explored to better simulate the in vitro three-dimensional (3D) system. This model may be applied to computed tomography data, which could help in understanding to what degree surface curvature controls many biological processes such as morphogenesis, growth, bone healing, bone remodelling and implant integration.



$$\frac{1}{R} = \frac{\kappa_1 + \kappa_2}{2} = \frac{16}{3r}\left(\frac{V}{V_{tot}} - \frac{1}{2}\right)$$

Figure 1. Principle of the 3D computational model. (a) On a 3D surface (example in grey), the local mean curvature is proportional to the fraction of a spherical mask centred in the point of interest that remains on the outer part of the surface (V represents the red part of the sphere, V_{tot} represents the total sphere volume, i.e. the sum of the red and yellow parts) (Bullard et al. 1995). (b) In order to model growth on a discrete lattice, we used a discretised spherical mask to scan the 3D arrays representing the pores. (c) A 3D array containing this volume fraction representing effective curvature values is derived. The figure shows what happens at different depths in a corner of a pore. (d) Growth laws are applied: 'the interface is moved until the effective curvature is null' or 'tissue (in orange) is deposited where the effective curvature is positive'. Growth is simulated by scanning the new 3D arrays obtained after each iteration step.