Année de publication : 2012

Paolo Maiuri, Emmanuel Terriac, Perrine Paul-Gilloteaux, Timothée Vignaud, Krista McNally, James Onuffer, Kurt Thorn, Phuong A Nguyen, Nefeli Georgoulia, Daniel Soong, Asier Jayo, Nina Beil, Jürgen Beneke, Joleen Chooi Hong Lim, Chloe Pei-Ying Sim, Yeh-Shiu Chu, , Andrea Jiménez-Dalmaroni, Jean-François Joanny, Jean-Paul Thiery, Holger Erfle, Maddy Parsons, Timothy J Mitchison, Wendell A Lim, Ana-Maria Lennon-Duménil, Matthieu Piel, Manuel Théry (2012 Sep 15)
The first World Cell Race.
Current biology : CB : R673-5 : DOI : 10.1016/j.cub.2012.07.052

Résumé

Natsuhiko Yoshinaga, Philippe Marcq (2012 Jul 13)
Contraction of cross-linked actomyosin bundles.
Physical biology : 046004 : DOI : 10.1088/1478-3975/9/4/046004

Résumé

Cross-linked actomyosin bundles retract when severed in vivo by laser ablation, or when isolated from the cell and micromanipulated in vitro in the presence of ATP. We identify the timescale for contraction as a viscoelastic time τ, where the viscosity is due to (internal) protein friction. We obtain an estimate of the order of magnitude of the contraction time τ ≈ 10-100 s, consistent with available experimental data for circumferential microfilament bundles and stress fibers. Our results are supported by an exactly solvable, hydrodynamic model of a retracting bundle as a cylinder of isotropic, active matter, from which the order of magnitude of the active stress is estimated.

J Ranft, J Prost, F Jülicher, J-F Joanny (2012 Jun 16)
Tissue dynamics with permeation.
The European physical journal. E, Soft matter : 46 : DOI : 10.1140/epje/i2012-12046-5

Résumé

Animal tissues are complex assemblies of cells, extracellular matrix (ECM), and permeating interstitial fluid. Whereas key aspects of the multicellular dynamics can be captured by a one-component continuum description, cell division and apoptosis imply material turnover between different components that can lead to additional mechanical conditions on the tissue dynamics. We extend our previous description of tissues in order to account for a cell/ECM phase and the permeating interstitial fluid independently. In line with our earlier work, we consider the cell/ECM phase to behave as an elastic solid in the absence of cell division and apoptosis. In addition, we consider the interstitial fluid as ideal on the relevant length scales, i.e., we ignore viscous stresses in the interstitial fluid. Friction between the fluid and the cell/ECM phase leads to a Darcy-like relation for the interstitial fluid velocity and introduces a new characteristic length scale. We discuss the dynamics of a tissue confined in a chamber with a permeable piston close to the homeostatic state where cell division and apoptosis balance, and we calculate the rescaled effective diffusion coefficient for cells. For different mass densities of the cell/ECM component and the interstitial fluid, a treadmilling steady state due to gravitational forces can be found.

Isabelle Bonnet, Philippe Marcq, Floris Bosveld, Luc Fetler, Yohanns Bellaïche, François Graner
(2012 May 26)

Mechanical state, material properties and continuous description of an epithelial tissue.

Journal of the Royal Society, Interface / the Royal Society : 2614-23 : DOI : 10.1098/rsif.2012.0263

Résumé

During development, epithelial tissues undergo extensive morphogenesis based on coordinated changes of cell shape and position over time. Continuum mechanics describes tissue mechanical state and shape changes in terms of strain and stress. It accounts for individual cell properties using only a few spatially averaged material parameters. To determine the mechanical state and parameters in the Drosophila pupa dorsal thorax epithelium, we severed in vivo the adherens junctions around a disc-shaped domain comprising typically a hundred cells. This enabled a direct measurement of the strain along different orientations at once. The amplitude and the anisotropy of the strain increased during development. We also measured the stress-to-viscosity ratio and similarly found an increase in amplitude and anisotropy. The relaxation time was of the order of 10 s. We propose a space-time, continuous model of the relaxation. Good agreement with experimental data validates the description of the epithelial domain as a continuous, linear, visco-elastic material. We discuss the relevant time and length scales. Another material parameter, the ratio of external friction to internal viscosity, is estimated by fitting the initial velocity profile. Together, our results contribute to quantify forces and displacements, and their time evolution, during morphogenesis.

Otger Campàs, L Mahadevan, Jean-François Joanny (2012 Mar 13)

Actin network growth under load.

Biophysical journal : 1049-58 : DOI : 10.1016/j.bpj.2012.01.030

Résumé

Many processes in eukaryotic cells, including the crawling motion of the whole cell, rely on the growth of branched actin networks from surfaces. In addition to their well-known role in generating propulsive forces, actin networks can also sustain substantial pulling loads thanks to their persistent attachment to the surface from which they grow. The simultaneous network elongation and surface attachment inevitably generate a force that opposes network growth. Here, we study the local dynamics of a growing actin network, accounting for simultaneous network elongation and surface attachment, and show that there exist several dynamical regimes that depend on both network elasticity and the kinetic parameters of actin polymerization. We characterize this in terms of a phase diagram and provide a connection between mesoscopic theories and the microscopic dynamics of an actin network at a surface. Our framework predicts the onset of instabilities that lead to the local detachment of the network and translate to oscillatory behavior and waves, as observed in many cellular phenomena and in vitro systems involving actin network growth, such as the saltatory dynamics of actin-propelled oil drops.

Benoît Sorre, Andrew Callan-Jones, John Manzi, Bruno Goud, Jacques Prost, Patricia Bassereau*, Aurélien Roux* (2012 Jan 3)

Nature of curvature coupling of amphiphysin with membranes depends on its bound density.

Proceedings of the National Academy of Sciences of the United States of America : 109 : 173-178 : DOI : 10.1073/pnas.1103594108

Résumé

Cells are populated by a vast array of membrane-binding proteins That execute critical functions. Functions, like signaling and intracellular transport require the abilities to bind to highly curved membranes and membrane deformation to trigger. Among proteins thesis is Amphiphysin 1 Implicated in clathrin mediated endocytosis. It contains a Bin-Amphiphysin Rvs-membrane-binding domain with an N-terminal amphipathic helix and senses That Generates membrane curvature. However, an understanding of the parameters distinguishing thesis two functions is missing. By pulling a highly curved nanotube radius of controlled from a giant vesicle in a solution Containing Amphiphysin, we Observed que la actions of the protein depends on icts Directly density on the membrane. At low densified of protein on the vesicle Nearly flat, the distribution of proteins and the mechanical effects are induced Described by a model based on spontaneous curvature induction. The tube radius and strength are modified by protein binding but still depends on membrane voltage. In the dilute limit, When Were Practically no proteins present on the vesicle, no mechanical effects Were detected, strong goal protein enrichment proportional to curvature Was seen on the tube. At high densified, the radius is independent of voltage and vesicle protein density, resulting and from the formation of a scaffold around the tube. As a result, the scaling of the power with voltage is modified. For the entire density range, protein enriched Was on the tube as Compared to the vesicle. Our approach shows que le strength of curvature sensing and mechanical effects on the tube depends on the protein density.

Année de publication : 2011

Jacques Prost (2011 Dec 24)

[But where are the genes?].

Médecine sciences : M/S : 1043-4 : DOI : 10.1051/medsci/20112712001

Résumé

Andrei S Kozlov, Thomas Risler, Armin J Hinterwirth, A J Hudspeth (2011 Nov 30)
Relative stereociliary motion in a hair bundle opposes amplification at distortion frequencies.
The Journal of physiology : 301-8 : DOI : 10.1113/jphysiol.2011.218362

Résumé

Direct gating of mechanoelectrical transduction channels by mechanical force is a basic feature of hair cells that assures fast transduction and underpins the mechanical amplification of acoustic inputs, but the associated non-linearity – the gating compliance – inevitably distorts signals. Because reducing distortion would make the ear a better detector, we sought mechanisms with that effect. Mimicking in vivo stimulation, we used stiff probes to displace individual hair bundles at physiological amplitudes and measured the coherence and phase of the relative stereociliary motions with a dual-beam differential interferometer. Although stereocilia moved coherently and in phase at the stimulus frequencies, large phase lags at the frequencies of the internally generated distortion products indicated dissipative relative motions. Tip links engaged these relative modes and decreased the coherence in both stimulated and free hair bundles. These results show that a hair bundle breaks into a highly dissipative serial arrangement of stereocilia at distortion frequencies, precluding their amplification.

Philippe Marcq, Natsuhiko Yoshinaga, Jacques Prost (2011 Sep 28)
Rigidity sensing explained by active matter theory.
Biophysical journal : L33-5 : DOI : 10.1016/j.bpj.2011.08.023

Résumé

The magnitude of traction forces exerted by living animal cells on their environment is a monotonically increasing and approximately sigmoidal function of the stiffness of the external medium. We rationalize this observation using active matter theory, and propose that adaptation to substrate rigidity results from an interplay between passive elasticity and active contractility.

E Hannezo, J Prost, J-F Joanny (2011 Sep 10)
Instabilities of monolayered epithelia: shape and structure of villi and crypts.
Physical review letters : 078104

Résumé

We study theoretically the shapes of a dividing epithelial monolayer of cells lying on top of an elastic stroma. The negative tension created by cell division provokes a buckling instability at a finite wave vector leading to the formation of periodic arrays of villi and crypts. The instability is similar to the buckling of a metallic plate under compression. We use the results to rationalize the various structures of the intestinal lining observed in vivo. Taking into account the coupling between cell division and local curvature, we obtain different patterns of villi and crypts, which could explain the different morphologies of the small intestine and the colon.

Matthieu Piel, Jean-François Joanny (2011 Jul 2)

[The rounding of mitotic cells].

Médecine sciences : M/S : 590-2 : DOI : 10.1051/medsci/2011276010

Résumé

Andrei S Kozlov, Johannes Baumgart, Thomas Risler, Corstiaen P C Versteegh, A J Hudspeth (2011 May 24)

Forces between clustered stereocilia minimize friction in the ear on a subnanometre scale.

Nature : 376-9 : DOI : 10.1038/nature10073

Résumé

The detection of sound begins when energy derived from an acoustic stimulus deflects the hair bundles on top of hair cells. As hair bundles move, the viscous friction between stereocilia and the surrounding liquid poses a fundamental physical challenge to the ear's high sensitivity and sharp frequency selectivity. Part of the solution to this problem lies in the active process that uses energy for frequency-selective sound amplification. Here we demonstrate that a complementary part of the solution involves the fluid-structure interaction between the liquid within the hair bundle and the stereocilia. Using force measurement on a dynamically scaled model, finite-element analysis, analytical estimation of hydrodynamic forces, stochastic simulation and high-resolution interferometric measurement of hair bundles, we characterize the origin and magnitude of the forces between individual stereocilia during small hair-bundle deflections. We find that the close apposition of stereocilia effectively immobilizes the liquid between them, which reduces the drag and suppresses the relative squeezing but not the sliding mode of stereociliary motion. The obliquely oriented tip links couple the mechanotransduction channels to this least dissipative coherent mode, whereas the elastic horizontal top connectors that stabilize the structure further reduce the drag. As measured from the distortion products associated with channel gating at physiological stimulation amplitudes of tens of nanometres, the balance of viscous and elastic forces in a hair bundle permits a relative mode of motion between adjacent stereocilia that encompasses only a fraction of a nanometre. A combination of high-resolution experiments and detailed numerical modelling of fluid-structure interactions reveals the physical principles behind the basic structural features of hair bundles and shows quantitatively how these organelles are adapted to the needs of sensitive mechanotransduction.

Markus Basan, Jean-François Joanny, Jacques Prost, Thomas Risler (2011 May 17)
Undulation instability of epithelial tissues.
Physical review letters : 158101

Résumé

Treating the epithelium as an incompressible fluid adjacent to a viscoelastic stroma, we find a novel hydrodynamic instability that leads to the formation of protrusions of the epithelium into the stroma. This instability is a candidate for epithelial fingering observed in vivo. It occurs for sufficiently large viscosity, cell-division rate and thickness of the dividing region in the epithelium. Our work provides physical insight into a potential mechanism by which interfaces between epithelia and stromas undulate and potentially by which tissue dysplasia leads to cancerous invasion.

Markus Basan, Jacques Prost, Jean-François Joanny, Jens Elgeti (2011 Apr 5)
Dissipative particle dynamics simulations for biological tissues: rheology and competition.
Physical biology : 026014 : DOI : 10.1088/1478-3975/8/2/026014

Résumé

In this work, we model biological tissues using a simple, mechanistic simulation based on dissipative particle dynamics. We investigate the continuum behavior of the simulated tissue and determine its dependence on the properties of the individual cell. Cells in our simulation adhere to each other, expand in volume, divide after reaching a specific size checkpoint and undergo apoptosis at a constant rate, leading to a steady-state homeostatic pressure in the tissue. We measure the dependence of the homeostatic state on the microscopic parameters of our model and show that homeostatic pressure, rather than the unconfined rate of cell division, determines the outcome of tissue competitions. Simulated cell aggregates are cohesive and round up due to the effect of tissue surface tension, which we measure for different tissues. Furthermore, mixtures of different cells unmix according to their adhesive properties. Using a variety of shear and creep simulations, we study tissue rheology by measuring yield stresses, shear viscosities, complex viscosities as well as the loss tangents as a function of model parameters. We find that cell division and apoptosis lead to a vanishing yield stress and fluid-like tissues. The effects of different adhesion strengths and levels of noise on the rheology of the tissue are also measured. In addition, we find that the level of cell division and apoptosis drives the diffusion of cells in the tissue. Finally, we present a method for measuring the compressibility of the tissue and its response to external stress via cell division and apoptosis.

T Guérin, J Prost, J-F Joanny (2011 Mar 17)
Motion reversal of molecular motor assemblies due to weak noise.
Physical review letters : 068101

Résumé

Bidirectional motion is an example of collective behavior of molecular motors. It occurs at finite noise level in a nonequilibrium system. We consider this problem as a first exit problem. We identify the noise strength by doing an expansion of a master equation and apply the Wentzell-Freidlin theory to define an effective nonequilibrium potential and provide analytical estimates of the reversal time. Our results match very well with the results of stochastic simulations.