BP 4: Tissue Mechanics I

Time: Monday 15:00–17:30 Location: BAR Schö

BP 4.1 Mon 15:00 BAR Schö

Nonlinear and active rheology of cell tissues — •Charlie Duclut[1,2], Joris Paijmans[2], Mandar M. Inamdar[3], Carl D. Modes[4], and Frank Jülicher[2] — [1]Laboratoire Physico-Chimie Curie, Paris, France — [2]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany — [3]Indian Institute of Technology Bombay, Mumbai, India — [4]Max Planck Institute for Molecular Cell Biology and Genetics, Dresden, Germany

Tissues are assemblies of large numbers of cells which form a soft active material. In amorphous solids as in tissues, neighbour exchanges (or T1 transitions) can relax local stresses and allow the material to flow. In tissues, in addition to these passive events, energy consumption at the microscopic level allows cells to perform active neighbour exchanges that can shape the tissue into a prescribed geometry. In my talk, I will consider an anisotropic vertex model to study T1 rearrangements in polygonal cellular networks. I will consider two different physical realizations of the active anisotropic stresses, that can be both observed in experiments: (i) anisotropic bond tension and (ii) anisotropic cell stress. Interestingly, the two types of active stress lead to patterns of relative orientation of T1 transitions and cell elongation that are different. Using the lens of a continuum description of the tissue as an anisotropic active material, I will discuss the energetics of the dynamic tissue and express the energy balance in terms of internal elastic energy, mechanical work, chemical work and heat. This allows us to define active T1 transitions that can perform mechanical work while consuming chemical energy.

BP 4.2 Mon 15:15 BAR Schö

Hydraulic and osmotic control of lumen coarsening — •Mathieu Le Verge Serandour[1,2] and Hervé Turlier[2] — [1]School of Natural Sciences, Technical University of Munich, Germany — [2]Center for Interdisciplinary Research in Biology, Collège de France, PSL Research University, Paris, France

The blastocoel formation is a keystone in the morphogenesis of the pre-implantation mammalian embryo, yet the physical mechanism for its emergence remained unclear. The blastocoel is a fluid-filled cavity (or lumen) that positions the first axis of symmetry of the embryo. We showed that, in the mouse embryo, the blastocoel results from micron-sized lumens, nucleating at the adhesive basolateral side of embryonic cells and coarsening in a process akin to Ostwald ripening. We investigate the collective dynamics of a one-dimensional chain of lumens as a minimal model for the blastocoel formation, taking the osmotic effects into account. We include the permeation of water and osmolyte through the cellular membrane. We show that the coarsening of the chain is reminiscent of dewetting films, with a scaling law for the number of lumens controlled by a screening length associated with water permeation, while the influence of osmotic inhomogeneities remains limited. Finally, we consider active osmolyte pumping that may rescue the chain from collapse. We find a new scaling law controlled by active pumping emerging from the coalescence of lumens, which may also direct the position of the final lumen.

BP 4.3 Mon 15:30 BAR Schö

Mechanical Properties of the Premature Lung — •Jonas Naumann[1], Nicklas Koppe[1], Ulrich Thome[2], Mandy Laube[2], and Mareike Zink[1] — [1]Research Group Biotechnology & Biomedicine, Peter Debye Institute for Soft Matter Physics, Leipzig University, 04103 Leipzig, Germany — [2]Center for Pediatric Research Leipzig, Department of Pediatrics, Division of Neonatology, Leipzig University, 04103 Leipzig, Germany

Premature infants are often reliant on mechanical ventilation to survive. However, prolonged ventilation and associated mechanical stress may cause subsequent pulmonary diseases of the immature lung. To study the mechanical properties of fetal rat lungs on macroscopic scale, we performed rheology experiments under compression and tension using different velocities. Fetal lung tissue showed a hyperelastic behavior and became significantly stiffer with increasing deformation velocities. In fact, fetal lung tissue under compression showed clear viscoelastic features even for small strains. A higher Young's modulus of fetal lungs compared to adult controls clearly pointed towards altered tissue characteristics. In addition, the influence of a hydrostatic pressure difference on the electrophysiology of primary fetal distal lung epithelial cells was investigated on microscopic scale. We observed a strong impact of hydrostatic pressure on the activity of the epithelial sodium channel and the sodium-potassium pump. Vectorial sodium transport, crucial for alveolar fluid clearance, was significantly impaired.

BP 4.4 Mon 15:45 BAR Schö

'Forcing' changes in health and disease: New access into bioengineered skeletal muscle mechanics for preclinical screening — •Arne Hofemeier[1,2], Till Muenker[2], Mariam Ristau[2], Timo Betz[2], and Wolfram Zimmermann[1] — [1]University Medical Center, Göttingen, Germany — [2]Third Institute of Physics, Göttingen, Germany

Mechanical properties of skeletal muscles are tightly related to proper functionality, which makes experimental access to the biomechanics of skeletal muscle tissue essential to advance our understanding of muscle function, development and disease. Recently devised in vitro culture systems allow for raising 3D muscle tissues using single cells from patients. However, these systems are inherently incompatible with high resolution microscopy and precise mechanical in-plate measurements. Here, we present a new chamber design that allows real-time high resolution 3D microscopy and non-invasive quantification of global contractile forces and tissue tension during muscle formation. Surprisingly, we found that bioengineered muscles, derived from patients suffering from Duchenne muscular dystrophy, develop under higher tension although they appear weaker upon stimulation. Duchenne is caused by loss of a membrane linker protein, dystrophin, which we therefore dedicate an important novel role as a molecular tension sensor. Testing an individualized gen therapy for a subset of Duchenne patients, we were able to demonstrate that not just the contractile strength of the bioengineered muscles was restored, but also the elevated tissue tension was decreased again.

15 min. break

BP 4.5 Mon 16:15 BAR Schö

Harnessing active viscoelasticity for synthetic epithelial morphogenesis — •Nimesh Ramesh Chahare[1,2], Adam Ouzeri[2], Tom Golde[1], Thomas Wilson[1,3], Pere Roca-Cusachs[1], Marino Arroyo[2,3], and Xavier Trepat[1,4] — [1]Institute for Bioengineering of Catalonia, Barcelona, Spain — [2]Universitat Politècnica de Catalunya, Barcelona, Spain — [3]Centre Internacional de Mètodes Numèrics en Enginyeria, Barcelona, Spain — [4]Institució Catalana de Recerca i Estudis Avançats, Barcelona, Spain

Epithelial sheets are active viscoelastic materials that form specialized 3D structures suited to their physiological roles, such as branched alveoli in the lungs, tubes in the kidney, and villi in the intestine. How epithelial shape arises from active viscoelasticity and luminal pressure remains poorly understood. Here we developed a microfluidic setup to engineer 3D epithelial tissues with controlled shape and pressure. Through this approach, we subject the tissues to a range of lumen pressures at different rates and probe the relation between strain and tension in different regimes. Slow pressure changes relative to the timescales of actin dynamics allow the tissue to accommodate large strain variations. However, under sudden pressure reductions, the tissue buckles and folds to store excess tissue area. This behavior is well captured by a 3D computational model that incorporates the turnover, viscoelasticity, and contractility of the actomyosin cortex. Informed by this model, we harness the active behavior of the cell cortex to pattern epithelial folds by rationally directed buckling. Our study establishes a new approach to engineering epithelial morphogenetic events.

BP 4.6 Mon 16:30 BAR Schö

Continuum Mechanics of Cell Intercalation in *Tribolium* — •Maryam Setoudeh[1,2,3] and Pierre A. Haas[1,2,3] — [1]Max Planck Institute for the Physics of Complex Systems, Nöthnitzer Straße 38, 01187 Dresden, Germany — [2]Max Planck Institute of Molecular Cell Biology and Genetics, Pfotenhauerstraße 108, 01307 Dresden, Germany — [3]Center for Systems Biology Dresden, Pfotenhauerstraße 108, 01307 Dresden, Germany

Deformations of tissues during development often involve cell intercalations and cell neighbour exchanges, but a general continuum description of such plastic rearrangements in tissues is still lacking.

Here, we combine morphoelasticity and plasticity theory to develop a continuum framework of tissue mechanics combining cell intercalations, intrinsic deformations such as tissue contraction, and elastic deformations of the tissue.

We apply our theory to the development of the beetle *Tribolium* [1] during which a layer of cells, the serosa, closes over the embryo. Cells deintercalate from the rim of the serosa into its bulk, thus reducing the number of cells at the boundary and closing the serosa. This is associated with actomyosin contraction at the rim of the serosa [1].

We model this process by the axisymmetric closure of a circular hole in a flat elastic sheet contracting near the hole. Our analytical and numerical results show how intercalation reduces the contraction required for serosa closure and hint at the importance of an additional force exerted by the embryo at the rim of the serosa.

[1] Jain *et al.*, Nat. Commun. **11**, 5604 (2020)

BP 4.7 Mon 16:45 BAR Schö

Tracking and comprehending single cell dynamics in Drosophila dorsal closure using machine learning — •Daniel Härtter[1,3], Yuxi Long[2], Janice Crawford[2], Daniel P. Kiehart[2], and Christoph F. Schmidt[1] — [1]Department of Physics and Soft Matter Center, Duke University, USA — [2]Department of Biology, Duke University, USA — [3]Department of Pharmacology and Toxicology, Göttingen University Medical Center

Dorsal closure in Drosophila melanogaster embryos is a key model system for cell sheet morphogenesis and wound healing. We pursue a data-driven approach to understand the emergence of organized behavior on tissue level from the stochastic dynamics of single cells across scales. We developed DeepTissue, a deep-learning-based algorithm to automatically and robustly detect and temporally track various single cell features: cell shapes, cell junction lengths, myosin intensities, and tissue topology. Epithelial cells in dorsal closure exhibit oscillations and contribute to progressive cell sheet movements, while showing a large variability in individual shapes, dynamics, and fates. Based on high-quality multi-parametric trajectories of 1000s of single cells, we use unsupervised machine learning techniques to detect and classify behavioral and structural phenotypes. Further we study how the behavior of single cells throughout closure is driven by deterministic and/or stochastic factors, with the aim to predict singular cell ingression events.

BP 4.8 Mon 17:00 BAR Schö

The role of intermediate filaments in stress resistance in 3D epithelial structures — •Tom Golde[1], Marco Pensalfini[2], Nimesh Chahare[1], Marino Arroyo[1,2], and Xavier Trepat[1,3,4] — [1]IBEC, Barcelona, Spain — [2]UPC, Barcelona, Spain — [3]UB, Barcelona, Spain — [4]ICREA, Barcelona, Spain

The safety belt hypothesis states that IFs are protecting cells from large and rapid deformations. However, typical experiments for stretching epithelial tissues only reach maximum strains of around 0.3. We developed a microfluidic device where an epithelial monolayer is grown on a porous surface with circular low adhesion zones. Upon applying hydrostatic pressure, the monolayer delaminates into a spherical cap (dome), generating tissue strains of more than 1 while individual cells are stretched up to strains of 9. We can image these 3D epithelial domes with high resolution, determine the tissue tension via Laplace law, and control the rate of inflation and deflation.

Using this approach with MDCK cells, we observed a striking reorganization of the keratin IF rim-and-spoke network into a central knot with thick, radially oriented bundles. Previous results by us and others hereby indicate a crucial role of actin-IF interactions. To better understand the mechanical principles of such transitions, we developed a multiscale computational model that simulates the interactions of keratin IFs with the nucleus, desmosomes, and the actin cortex. Combining experiments and simulations, we can now conclusively test the safety belt hypothesis in controlled and unparalleled large 3D tissue deformations

BP 4.9 Mon 17:15 BAR Schö

Instabilities in hexanematic models of epithelia — •Josep-Maria Armengol-Collado, Livio Carenza, and Luca Giomi — Instituut-Lorentz, Leiden Institute of Physics, Universiteit Leiden, P.O. Box 9506, 2300 RA Leiden, The Netherlands

Epithelial tissues, whose study remain fundamental to understand processes such as cancer progression, have revealed to exhibit multiscale orientational order. While the large scale dynamics is ruled by the nematic symmetry, hexatic order instead controls the behaviour of small clusters of cells. By considering a hydrodynamic approach, we investigate the stability of hexanematic liquid crystals identifying the role of activity and flow alignment in the generation of spontaneous flows, which also reflect the interplay between different length scales. We finally address possible consequences when confining such a fluid in a channel, connecting this phenomenology with recent observations of metastatic cell invasion.