BP 27: Cell Mechanics I

Time: Thursday 9:30–12:45 Location: BAR/0205

Invited Talk BP 27.1 Thu 9:30 BAR/0205

Tissue interplay and the coordination of morphogenesis — •Elias Barriga — Physics of Life (PoL), Dresden, Germany

How tissues achieve robust morphogenesis in development and regeneration is the driving question in our research. In my talk I will share our results arising from a combination of mechanical and electrical measurements and perturbations in living tissues; and will discuss how our work support the exciting idea that biophysical properties emerging from tissue interplay coordinate morphogenesis in time and space.

BP 27.2 Thu 10:00 BAR/0205

Mechanical polarity in cell migration — •Steffen Grosser[1], Leone Rossetti[2], Isabela Corina Fortunato[3], Ricard Alert[4,5], and Xavier Trepat[1,5,6,7] — [1]Institute for Bioengineering of Catalonia (IBEC), Barcelona — [2]Faculty of Dentistry, Oral & Craniofacial Sciences, King's College, London — [3]Institut d'Investigació Sanitària Illes Balears (IdISBa), Palma — [4]MPI für Physik komplexer Systeme (MPI-PKS), Dresden — [5]University of Barcelona, Barcelona — [6]ICREA, Barcelona — [7]CIBER-BBN, Barcelona

Cells migrate on substrates in the absence of any net force, which poses a fundamental challenge in cell dynamics. All forces transmitted from the cells to the substrate cancel out. Neither force magnitude nor force dipole are related to neither cell speed nor direction.

We have recently found, however, that a higher moment of the cell traction distribution, the quadrupole, is in fact closely related to cell velocity - to both speed and direction. The quadrupole characterizes the asymmetry of the traction distribution, even when the total net force cancels out. It can be thought of as a mechanical cell polarity readout. Experimentally, the relation between force asymmetry and velocity holds for single cells and for short multicellular trains, and even for cells moving along gradients of adhesion.

To interpret this traction asymmetry, we propose to decompose the force into an active, unbalanced part that drives cell motion, and a frictional component. This leads to a novel, actual force-velocity relation for cell dynamics.

BP 27.3 Thu 10:15 BAR/0205

Mechanics of "apical bulkheads" in the bile canaliculi of the liver — •Matthew J. Bovyn[1,2,3], Maarten P. Bebelman[2], Yannis Kalaidzidis[2], Marino Zerial[2,4], and Pierre A. Haas[1,2,3] — [1]Max Planck Institute for the Physics of Complex Systems, Dresden — [2]Max Planck Institute of Molecular Cell Biology and Genetics, Dresden — [3]Center for Systems Biology Dresden — [4]Human Technopole, Milan

In the liver, bile is transported through the network of bile canaliculi. They are bicellular tubes ("lumina"), in which the apical cortices of apposed cells bear bile pressure. When bile canaliculi must hold high pressures, either in development or disease, they generate folds protruding into the tubes, termed "apical bulkheads". These structures are under tension and contribute significantly to the ability of the bile canaliculus as a whole to bear pressure [1]. Here, we use lightsheet microscopy to discover that bulkheads are also dynamic, forming and retracting on a timescale of 20 min. We investigate the mechanical origins of this process by constructing a mechanical model balancing pressure and anisotropic surface tensions and spontaneous curvature of the apical cortices. We discuss the cell biological origins of these mechanical ingredients, the experimental evidence for them, and their role in bulkhead formation.

[1] Bebelman, M. P., Bovyn, M. J., *et al.* Hepatocyte apical bulkheads provide a mechanical means to oppose bile pressure. J. Cell Biol. **222**, e202208002 (2023).

BP 27.4 Thu 10:30 BAR/0205

Blebbing under confinement functions as a pressure-relief mechanism following cortical contraction — •Fatemeh Abbasi[1,2], Timo Betz[2], and Eva Kiermaier[1,3,4] — [1]Life and Medical Sciences (LIMES) Institute, Immune and Tumor Biology, University of Bonn, Bonn, Germany. — [2]Third Institute of Physics-Biophysics, Georg August University Göttingen, Göttingen, Germany. — [3]Department of Medicine, Friedrich-Alexander University Erlangen-Nürnberg (FAU), Erlangen, Germany. — [4]Deutsches Zentrum Immuntherapie (DZI), Universitätsklinikum Erlangen, Erlangen, Germany.

Cells migrating through tissues experience mechanical confinement that reshapes their morphology and internal stress. Using Confinement Force Microscopy (CFM), we dynamically controlled vertical confinement during live imaging and quantified 3D stress responses. A single confinement step triggered a biphasic response: an immediate passive stress spike from nuclear compression followed by a slower, actomyosin-driven buildup linked to bleb formation. Both blebbistatin and Y-27632 reduced traction stresses; notably, Y-27632 fully blocked blebbing, while blebbistatin allowed it only under strong compression, indicating partial decoupling between contractility and morphology. Blebbistatin also lowered cellular stiffness and viscosity, promoting rapid stress relaxation. These results suggest that blebbing functions as a pressure-relief mechanism allowing cells to maintain mechanical balance under confinement.

BP 27.5 Thu 10:45 BAR/0205

Moving without motors: Amoeboid cell migration and shape dynamics driven by actin polymerization — •Winfried Schmidt, Alexander Farutin, and Chaouqi Misbah — Univ. Grenoble Alpes, CNRS, LIPhy, F-38000 Grenoble, France

Mammalian cell migration is essential for many physiological and pathological processes, such as embryonic development, wound healing, and cancer metastasis. Cells have developed the amoeboid migration mode, which is characterized by large, dynamic shape deformations. This strategy allows cells to move rapidly and in the absence of strong adhesion across a variety of different environments, including two-dimensional confinement, three-dimensional matrix, and bulk fluids. Molecular motors, such as myosin, are traditionally considered essential for cell polarization or motility. Here, a model of an amoeboid cell is analyzed both analytically and numerically. It is shown that actin polymerization alone is sufficient to trigger both cell polarity and motility, in line with recent experiments on T-lymphocytes showing that inhibition of molecular motors does not significantly affect motility. Depending on parameter values, the cells exhibit straight, circular, or even chaotic trajectories. A similar variety of motion is observed in experiments across multiple motile cells. These findings open up a new perspective on amoeboid motility, providing a scenario for the onset of polarity, migration, and dynamical cell shape changes without contractile activity.

15 min. break

BP 27.6 Thu 11:15 BAR/0205

Living Cells Respond to the Surface Tension of Soft Solids — •Johannes Rheinlaender, Leah Gumbsch, Hendrik von Eysmondt, and Tilman E. Schäffer — Institute of Applied Physics, University Tübingen, Germany

It is widely known that living cells respond to the stiffness of their environment in terms of spreading area as well as other properties such as the cytoskeletal structure, migration, or gene expression. These effects are usually investigated by seeding cells on elastic substrates with varying bulk stiffness, either hydrogels or soft elastomers. However, cellular behavior differs on hydrogels and elastomers, which has been attributed to various material properties like surface roughness or porosity. Using scanning ion conductance microscopy (SICM), we show that elastomers routinely used in mechanobiology studies exhibit a significant surface tension on the order of several tens of mN/m, independent of their bulk stiffness. We thereby demonstrate that living cells mostly respond to the surface tension rather than the bulk stiffness of the substrate on soft elastomers with Young's moduli below approximately 10 kPa and introduce possible solutions to address this problem. To conclude, the influence of surface tension is an important yet underestimated aspect in cellular mechanobiology.

BP 27.7 Thu 11:30 BAR/0205

Complex Rheology in Single Cells: Compression Stiffening but Shear Softening — •James P. Conboy[1], Luis Alonso[2], Haiqian Yang[2], Nicole van Vliet[1], Pouyan E. Boukany[1], Fred C. MacKintosh[3], and Gijsje H. Koenderink[1] — [1]TU Delft, NL — [2]MIT, USA — [3]Rice University, USA

In multicellular organisms, cells are constantly subjected to physical

forces. Cells in the heart, lungs and skin experience primarily compression and stretching, whereas shear forces are dominant in the brain and in blood vessels. The mechanical resilience to compression and shear forces is essential for preventing cell damage or even rupture. Our aim is to understand the response of cells to external mechanical cues. For this purpose, we have developed a novel single cell rheology setup that allows us for the first time to make direct comparisons between a living mammalian cell's response to compression and shear strain. In this work, we have identified the relative contribution of actin and vimentin intermediate filaments in uniaxial compression experiments on single fibroblasts. Our findings reveal that individual fibroblasts undergo stiffening under physiologically relevant compressive strains, but the removal of vimentin reduces this stiffening effect. Furthermore, we present, to our knowledge, the pioneering example of single-cell shear rheology experiments, where we discovered that cells soften when sheared, in stark contrast to their stiffening behaviour under compression. Finally, we propose a minimal model to elucidate these phenomena and compare our results to semiflexible polymer models used to explain the mechanics of reconstituted cytoskeletal systems.

BP 27.8 Thu 11:45 BAR/0205

Intracellular ROS generation under ultra-high dose rate electron irradiation at FLASHlab@PITZ — •Y. Komar[1,2,3], E. Fujan[2], C Richard[1], X. Li[1], N. Aftab[1], A. Aksoy[1], Z. Amirkhanyan[1], A. Chiravuri[1,2], J. Good[1], M. Gross[1], F. Hausmann[3], S. Khammee[1], M. Krasilnikov[1], B. Li[1], Z. Lotfi[1], G. Montoya-Soto[1], F. Müller[1], A. Oppelt[1], F. Riemer[1], K. Suzart[1], E. Tarakci[1,2,3], I. Tinhofer[3], D. Villani[1], S. Worm[1], D. Xu[1], S. Zeeshan[1], M. Frohme[2], F. Stephan[1], S. Aminzadeh[1,2], and A. Grebinyk[1,2] — [1]Deutsches Elektronen-Synchrotron, Zeuthen, Germany — [2]Technical University of Applied Sciences Wildau, Wildau, Germany — [3]Charité University Medicine Berlin, Corporate Member of Freie Universität Berlin and Humboldt-Universität zu Berlin, Berlin, Germany

The new FLASHlab@PITZ beamline commissioning started in August 2025 for radiobiological studies at the Photo-Injector Test Facility at DESY in Zeuthen (PITZ). It enables irradiation with dose rates ranging from conventional (CDR, 0.05Gy/s) up to ultra-high (UHDR, 10^14Gy/s). The in vitro effects of UHDR versus CDR irradiation were examined using human lung cancer A549 and healthy HEL299 cells exposed to CDR (0.05Gy/s) and UHDR (7.8*10^5Gy/s). Reactive oxygen species production assessment showed 84% decrease in HEL299 cells and no difference in A549 at ~7.5Gy under UHDR compared with CDR. That indicates UHDR irradiation having a milder impact on healthy than on cancer cells, highlighting the potential of FLASHlab@PITZ for future in vivo studies.

BP 27.9 Thu 12:00 BAR/0205

Probing the influence of mechano-chemical cues on the size of nuclei — •Pooja Yadav, Florian Rehfeldt, and Matthias Weiss — University of Bayreuth, Experimental Physics I,95447,Bayreuth

The size of nuclei in eukaryotes is frequently observed to scale with the size of the cell that harbours them. Yet, our understanding of how cells can measure and regulate nuclear size is still fragmentary. A recently developed model suggests nuclear size to be determined by a dynamically maintained but limited amount of membrane material that needs to be distributed between organelles and the plasma membrane. Given that membrane homeostasis and cell morphology can be altered biochemically and mechanically, we have used drug treatments and polyacrylamide (PA) hydrogels of varying stiffness as a substrate for cells. As a result, we have found that softening the substrate alters the shape and size of cells and nuclei, but maintains the ratio of their projected areas. Similarly, affecting the actomyosin cortex had little effect on this ratio. However, when enforcing changes in membrane homeostasis by pharmaceuticals, the ratio of cellular and nuclear cross-sectional areas was markedly altered. Altogether, our data suggest that dynamically maintaining and limiting membrane material is a core mechanism of how cells determine the size of their nuclei.

BP 27.10 Thu 12:15 BAR/0205

Nuclear downsizing: Dynamic volume and cell-cycle control in emerging tumour spheroids — •Vaibhav Mahajan[1], Keshav Gajendra Babu[1], Markus Mukenhirn[1], Antje Garside[1], Timon Beck[1,2], Byung Ho Lee[3], Kyoohyun Kim[2], Carsten Werner[4], Alf Honigmann[1], Sebastian Aland[5], Raimund Schlüssler[1], and Anna Taubenberger[1,4] — [1]Dresden University of Technology, Dresden, Germany — [2]Max Planck Institute for the Science of Light, Erlangen — [3]MPI-CBG, Dresden — [4]Leibniz Institute of Polymer Research Dresden — [5]Hochschule für Technik und Wirtschaft Dresden

Tumour development involves biophysical changes across scales, yet how cancer cells regulate properties such as volume and mechanics within dense multicellular environments remains unclear. Using tuneable biohybrid hydrogels, we quantified cell and nuclear volumes as single cancer cells formed multicellular tumour spheroids. We found that transition to multicellularity led to strong reductions in cellular and nuclear volumes, delayed cell-cycle progression, and altered mechanics, with these changes tightly coupled. Nuclear volume dropped by up to 60%, not primarily due to confinement but due to cell-cycle adaptations, namely accumulation of smaller-sized G1 cells-an effect reversed by CDK1 inhibition. Additional nuclear volume decreases within clusters were associated with increased mass density and cell stiffness, both reversible upon cell release. Conversely, cells invading out of spheroids increased nuclear volumes and softened. These findings reveal how cancer cells dynamically adjust volume, cell-cycle state, and mechanics in the multicellular context.

BP 27.11 Thu 12:30 BAR/0205

A protein-DNA surface hydrogel mechanically reinforces the cell nucleus — •Yahor Savich[1,2,3], Ramesh Adakkattil[1], Pranay Mandal[1,2,3], Valentin Ruffine[4], Mareike Jordan[1], Henrik Dahl Pinholt[5], Elisabeth Fischer Friedrich[4], Frank Jülicher[2,3,4], Stephan Grill[1,3,4], and Alexander von Appen[1,4] — [1]MPI-CBG, Dresden — [2]MPI-PKS, Dresden — [3]Center for Systems Biology Dresden — [4]TUD, Dresden — [5]MIT, Cambridge

Cells safeguard their genome while nuclei are deformed. The nuclear envelope is known to protect DNA from such mechanical stress, but how forces are buffered across the scales from individual DNA strands to the nucleus remains unknown. We show that the nuclear envelope protein LEM2 and the DNA-binding protein BAF, together with DNA, form an unconventional stiffening system. When DNA is held at a given force in optical tweezers, the addition of these proteins causes a force increase proportional to the initial force. This behaviour can be captured by an effective spring model that emerges from multivalent protein-protein and protein-DNA interactions. At the nuclear surface, the same components form an elastic surface hydrogel in which the multivalent interactions contract the surface hydrogel relative to its relaxed state, introducing a pre-stress. Using parameters obtained at the molecular scale, a continuum model of this surface hydrogel yields free-energy-minimizing nuclear shapes and an area stiffness that are in agreement with measurements in control and LEM2 knockdown cells. These results identify a load-bearing, mesoscale protein-DNA surface hydrogel that mechanically reinforces the nucleus.