BP 9: Poster Session Ib

Cell Mechanics. Additional posters on Cell Mechanics in Poster Session Ia.

Time: Monday 18:00–20:30 Location: Poster D

BP 9.1 Mon 18:00 Poster D

Substrate functionalization reveals the electrostatic nature of flagellar adhesion to surfaces — •Lea Rupprecht[1], Rodrigo Catalan[1], Antoine Girot[1], Christian Kreis[2], and Oliver Bäumchen[1,2] — [1]University of Bayreuth, Experimental Physics V, 95447 Bayreuth, Germany — [2]Max Planck Institute for Dynamics and Self-Organization (MPIDS), Am Fassberg 17, 37077 Göttingen, Germany

Elucidating the physical phenomena underlying the interactions between microorganisms and surfaces is crucial for the development of technologies that aim to control the formation of microbial biofilms. While most of the studies use bacteria as model organisms, the principles of microbial adhesion remain elusive for eukaryotic photosynthetic microorganisms. We recently discovered that the model unicellular microalga *Chlamydomonas reinhardtii* adheres to surfaces by means of its two flagella under specific light conditions [Kreis *et al.*, Nature Physics, 2018]. Using *in vivo* single-cell micropipette force spectroscopy, we characterized the adhesion forces on surface-functionalized substrates in order to dissect the influence of surface energy, hydrophobicity, long-ranged van der Waals and electrostatic interactions [Kreis *et al.*, Soft Matter, 2019]. We found that the flagellar adhesion of *C. reinhardtii* cells to surfaces is unspecific and predominantly governed by electrostatic interactions. Here, we present adhesion force measurements of *C. reinhardtii* on surfaces with tailored electrostatic interactions, e.g. poly-L-lysin-coated silicon wafers.

BP 9.2 Mon 18:00 Poster D

An analytical theory of the influence of a cell nucleus on cell deformation — •Clara Gremmelspacher and Stephan Gekle — Universität Bayreuth

We develop an analytical theory to investigate the influence of a nucleus on cell deformation under mechanical load. To do this, we use linear elasticity theory and compare the deformation of homogeneous and heterogeneous cells under different boundary conditions. From these calculations we aim at deriving effective elasticity moduli of these shell-nucleus systems. Our work is intended to give a theoretical background to the often used practice of simplifying cells with their complex internal structure as homogeneous cells in numerical simulations and experimental data analysis.

BP 9.3 Mon 18:00 Poster D

Investigation of cortex-membrane interactions forming cell stiffness — •Tim Kutz[1], Andreas Janshoff[2], and Timo Betz[1] — [1]Third Institute of Physics, Georg August Universität Göttingen, Göttingen, Germany — [2]Institute of Physical Chemistry, Georg August Universität Göttingen, Göttingen, Germany

Cellular stiffness, a critical aspect of cell mechanics, influences cellular functions, like migration or responses to external stimuli. However, the precise origin of cellular and in particular cortical stiffness remains a subject of intensive investigation. Deciphering whether the stiffness of the cell surface predominantly arises from the cell membrane, the actin cortex beneath the membrane, or a synergistic combination of both is essential for advancing our knowledge of cell mechanics. To address this challenge, we propose a comprehensive approach that combines atomic force microscopy (AFM), confocal spinning disk fluorescence microscopy (CSDFM), and micropipette aspiration. AFM allows for high-resolution topographical imaging, offering nanoscale insights into the mechanical properties of the cell membrane and the underlying actin cortex. Simultaneously, CSDFM provides dynamic 3D visualization of cellular processes, augmenting our understanding of the structural components influencing cellular mechanics. The integration of micropipette aspiration complements these techniques by directly manipulating mechanical forces applied to the cell. This multi-modal approach not only enhances the precision and depth of our biomechanical analyses but also enables the correlation of structural and dynamic information, providing a holistic perspective on cellular mechanics.

BP 9.4 Mon 18:00 Poster D

Spatially varying cell fitness induced by confinement geometry and alignment — •Patrick Zimmer[1,2], Yoav G. Pollack[1,2], Philip Bittihn[2], and Ramin Golestanian[2,3] — [1]University of Göttingen, Göttingen, Germany — [2]Max Planck Institute for Dynamics and Self-Organization (MPI-DS), Göttingen, Germany — [3]University of Oxford, Oxford, UK

Competition of cell phenotypes for limited space plays a role in both development and in tumor progression (healthy-cancerous / cancerous-cancerous clones). We focus here on purely non-adversarial competition dominated by stochastic fluctuations, avoiding any 'killing' related advantage.

Predicting the outcome for competition of such growing active matter is non-trivial, as it depends on how cell turnover via growth, proliferation and the degradation of cellular matter is regulated by mechanosensing in confinement.

We show that in a circular confinement, fitness of clones varies in the edge compared to the center correlated with layering, polar order of cell alignment and pressure modulation.

BP 9.5 Mon 18:00 Poster D

Optimize Microfluidic Synthesis of Polymer Beads for In-Vivo Force Cell Sensing — •Jordan Dieter Groh, Alejandro Jurado Jiménez, and Timo Betz — Drittes Physikalisches Institut, Göttingen, Deutschland

Since the first use of deformable beads inside living tissue as force sensors some ten years ago, the technique has been refined with the introduction of new materials and methods to measure deformation. Specially in our lab, polyacrylamide beads have been extensively used to assess forces in all kinds of in-vivo an in-vitro systems such as developing embryos, cancer spheroids or reconstituted muscle tissue. However, using shear-induced emulsions as fabrication method still presents some limitations: a broad size distribution and small variations in polymer stiffness. This project aims to optimize the production of polyacrylamide beads in two ways. First, the adoption of flow-focusing. This microfluidics technique is commonly employed in diverse fields, including drug delivery and the food industry, for creating emulsions with precise control over droplet sizes. Secondly, the use of UV-light as polymerization initiator. These two approaches should massively improve the reproducibility of our experiments, creating more homogeneous batches for measurements.

BP 9.6 Mon 18:00 Poster D

Measuring Mean Back Relaxation with Dark-field Microscopy — •Julian Schulz — Georg August Universität, Göttingen, Germany

The measurement of mechanical properties in living cells presents significant challenges due to their non-equilibrium nature. Traditional methods, such as active rheology, assess the complex shear modulus and energy dissipation but require challengingly complex invasive experiments. In contrast, the "mean back relaxation" (MBR), a novel statistical measure introduced by Muenker, Knotz, Krüger & Betz in 2022, offers insights into the energy dissipation of a cell through purely passive observations. So far, MBR measurements have relied on optical tweezers-based particle tracking, a technique not readily accessible in many laboratories. In this work, we utilize broadly available dark-field microscopy to monitor the position of a tracer particle inside hydrogels or cells with high spatial and temporal resolution. By comparing the results from this method with simulations, we can align them with various viscoelastic models, thereby enabling the determination of biomechanical properties of cells. Our approach significantly enhances the accessibility of MBR measurement, providing a high-throughput method suitable for a broader range of laboratories. Furthermore, we offer software tools for efficient data analysis, expanding the potential for MBR measurements in diverse research settings. This advancement allows more scientists to explore cellular mechanics with less specialized equipment and reduced overhead.

BP 9.7 Mon 18:00 Poster D

Using cell shape measurements to classify *in vivo* resident tissue macrophage morphology in health and disease — •Miriam Schnitzerlein[1,2], Anja Wegner[3,4,5], Stefan Uderhardt[3,4,5], and Vasily Zaburdaev[1,2] — [1]Department Biology,

Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU) — [2]Max-Planck-Zentrum für Physik und Medizin, Erlangen — [3]Department of Medicine 3 - Rheumatology and Immunology, FAU und Universitätsklinikum Erlangen — [4]Deutsches Zentrum für Immuntherapie, FAU — [5]Exploratory Research Unit, Optical Imaging Competence Center Erlangen, FAU

Resident tissue macrophages (RTMs) are a type of immune cell present in essentially all tissues in the human body. One of their main functions is to keep the tissue in homeostasis by removing dead cells or resolving lesions, thereby preventing unnecessary inflammation. To find such incidents, RTMs show continuous sampling behaviour by extending and retracting their protrusions which changes their overall morphology accordingly. Thus, these morphology changes can act as an indicator of a specific activation state of RTMs. In this project, we have employed a high-resolution, intravital imaging protocol to generate dynamic data of murine RTMs *in vivo* in the peritoneum. Next we have built a custom image processing pipeline to assess RTM morphology and dynamics via a set of cell size and shape features. Our features can quantitatively distinguish differently activated RTMs induced by various chemical stimuli. Furthermore, we could use our quantifiers to improve the health of RTMs in different experimental settings *ex vivo*.

BP 9.8 Mon 18:00 Poster D

Adhesion-based active gel model for 1D cell migration — •Valentin Wössner, Oliver M. Drozdowski, Falko Ziebert, and Ulrich S. Schwarz — Institute for Theoretical Physics and BioQuant, Heidelberg University, 69120 Heidelberg

Active gel theory has demonstrated that actomyosin contractility is sufficient for polarization and self-sustained cell migration in the absence of external cues. However, in these models, the dynamic character of substrate adhesion is usually neglected, although it seems to play an important role in more complex migration modes and during motility initiation. Simple models based on bond dynamics have been suggested for the required adhesion dynamics, but these do not include intracellular flows. Here we show that, in a one-dimensional setting, active gel theory can be extended by such adhesion dynamics and that load sharing is the cooperative effect that is required to obtain symmetry breaking. For intermediate adhesiveness, symmetric actin polymerization then leads to robust motility in a bistable regime. Our model predicts adhesion and flow profiles in qualitative agreement with experimental results. We also study switching between sessile and motile states by applying nonlinear perturbations as well as cell behavior on adhesive pattern.

BP 9.9 Mon 18:00 Poster D

Metal Induced Energy Transfer for height analysis of actin architecture under shear stress — •Michelle Denise Schoft, Carolin Grandy, Jonas Pfeil, and Kay-Eberhard Gottschalk — Institut für Experimentelle Physik, Universität Ulm, Ulm, Germany

Cells interact with their environment by responding to mechanical and biochemical signals. The focal adhesion multi-protein complex provides a link between the extracellular environment and the actin cytoskeleton. Aside from adherence to the surface, focal adhesions are relevant in sensing and transduction of mechanical cues. This is initially mediated via integrins, the transmembrane proteins associated with focal adhesion complexes, linking the external environment to further internal force-sensitive proteins. To analyse the effect of mechanical stress on the actin architecture of 3T3 fibroblasts, a range of different shear stress levels was applied in a perfusion setup. Moreover, to determine the influence of integrins in mechanosignaling under fluid flow, the experiment was performed with fibroblasts expressing the fibronectin-binding $\alpha_5\beta_1$, $\alpha_v\beta_3$ and $\alpha_5\beta_1/\alpha_v\beta_3$ integrin variants. The height data of the actin organisation was aquired by Metal Induced Energy Transfer recorded with Fluorescent Lifetime Imaging Microscopy (FLIM) on a gold surface. We use this technique to achieve nanoscale resolution of the axial actin organisation.

BP 9.10 Mon 18:00 Poster D

Modeling durotaxis in living cells on alternating substrate stiffness: a boltzmann approach — •Mathis Grelier[1], Carlos Ureña martin[2], Mark Schvartzman[2], and Ana-Sunčana Smith[1,3] — [1]PULS Group, Institute for Theoretical Physics and Interdisciplinary Center for Nanostructured Films (IZNF), Friedrich-Alexander Universität Erlangen-Nürnberg (FAU), 91058 Erlangen, Germany — [2]Department of Materials Engineering and Ilse Katz Institute for Nanoscale Science & Technology, Ben-Gurion University of the Negev, Beer-Sheva 84105, Israel — [3]Group of Computational Life Sciences, Division of Physical Chemistry, Ruder Bošković Institute, 10000 Zagreb, Croatia

Understanding cellular responses to substrate stiffness is crucial for unraveling fundamental principles of cell spreading and migration. Our study investigates durotaxis in HeLa cells by conducting experiments on substrates featuring alternating lines of distinct stiffness. To describe the cell spreading, we introduce a stochastic model grounded in a Boltzmann distribution. This comprehensive framework considers different energy contributions governing the stochastic spread of cells over line boundaries. We observe a higher alignment of cells along the lines when the width of the softest lines increases. This behavior arises due to the increasing energy expenditure incurred by the cell when attempting to bridge across the softer substrate. The model successfully captures the probability distribution of cell shapes and alignment of the experiments, providing a quantitative framework for predicting the biomechanics of cell migration over material of different stiffness.

BP 9.11 Mon 18:00 Poster D

Interpretation of cell mechanical experiments in microfluidic systems depends on cellular shape descriptors — •Bob Fregin, Doreen Biedenweg, and Oliver Otto — Institute of Physics, University of Greifswald, Greifswald, Germany

Mechanical properties of cells are known to be linked to cell state, fate, and function. For identifying and tracking cells, as well as quantifying their deformations, it is crucial to accurately characterize cell shapes. While various shape descriptors have been explored for studying adherent cell morphology, their impact on rheological experiments involving suspended cells remains less understood. Here, we compared nine shape descriptors to quantify suspended cell deformation under extensional and shear flow in a microfluidic system using dynamic real-time deformability cytometry. Our findings reveal that while stress relaxation depends on stress amplitude and duration, steady-state deformation can be predicted from single-cell traces, even for short translocation times. By comparing data analysis strategies, we explored the balance between computational costs and experimental accuracy. Our results suggest that such measurements are feasible on an ensemble scale when the characteristic time matches the microfluidic system's dimensions. Additionally, we introduced a scoring method to evaluate shape descriptor-dependent effects on cell deformation after cytoskeletal modifications. We found that analyzing cells in extensional flow offers higher sensitivity, irrespective of shape parameterization, while inverse Haralick's circularity is more suited for studying cells in shear flow.

BP 9.12 Mon 18:00 Poster D

Virtual fluidic channels as liquid tweezer for mechanocytometry — •Karolin Melde[1], Doreen Biedenweg[1], Salvatore Girardo[2], Horst-Holger Boltz[1], Thomas Ihle[1], and Oliver Otto[1] — [1]Institute of Physics, University of Greifswald, Greifswald, Germany — [2]Max Planck Institute for the Science of Light, Erlangen, Germany

Real-time deformability cytometry is a high-throughput method to study the mechanical properties of single cells. Utilizing hydrodynamic shear and normal stresses, micron-sized objects are deformed within a microfluidic channel of dimensions that have to match the cell size.
To overcome this limitation, we recently introduced virtual fluidic channels (VFCs) that enable tailoring the microfluidic geometry within seconds. VFCs are formed by co-flowing aqueous polymer solutions, where cells are confined between the corresponding liquid-liquid interfaces that act as a pair of tweezers. Interestingly, these liquid tweezers impose a normal stress on cells that cannot be understood from bulk interfacial tension, but that is sufficient to induce cell deformation.
Here, we aim to study the physics of this liquid-liquid interface by introducing calibration particles in the form of oil droplets and hydrogel beads. While the latter possess a Young's modulus of 1.4 - 1.6 kPa, the surface tension of the oil droplets was characterized using a ring tensiometer. Preliminary experiments show that both particles can be deformed by the pair of liquid tweezers. We plan to build upon these initial results and examine the impact of different flow rates and polymer compositions on interfacial stability and stress.

BP 9.13 Mon 18:00 Poster D

Investigating the mechanical regulation of axon growth in three-dimensional matrices — •Niklas Gampl[1,2] and Kristian Franze[1,2,3] — [1]Max-Planck-Zentrum für Physik und Medizin, Erlangen, Germany — [2]Institute of Medical Physics and Microtissue Engineering, Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlan-

gen, Germany — [3]Department of Physiology, Development and Neuroscience, University of Cambridge, Cambridge, UK

During brain development, neurons extend long axons, which grow along well-defined pathways to their destination. This axon pathfinding is known to be regulated by chemical guidance cues which are produced by neuroepithelial cells. However, Xenopus retinal ganglion cell axons have additionally been shown to actively probe their mechanical environment in vivo and when cultured on 2D substrates. To study this mechanical regulation in 3D environments with tunable stiffness, we developed a framework to culture Xenopus eye primordia in collagen-based hydrogels. We characterised the mechanical and topological properties of these matrices for different collagen concentrations and used them to mimic the mechanical environment neurons encounter in vivo during early embryonic development. We found that axon length was reduced in stiff (G' = 450 Pa) compared to soft (G' = 40 Pa) hydrogels and that growth cones, the motile tips of axons, exert contractile forces of up to 2 nN on their 3D environment. Further investigation of the mechanical and chemical regulation of axon growth in 3D environments could improve our understanding of the complex interplay between guidance cues and their integration by cells.

BP 9.14 Mon 18:00 Poster D

Investigating effective cell membrane tension and its dependence on substrate stiffness — •Julia Butzke[1], Tina Boric[1], Eva Kreysing[1,3], and Kristian Franze[1,2,3] — [1]Institute of Medical Physics and Microtissue Engineering, Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen, Germany — [2]Max-Planck-Zentrum für Physik und Medizin, Erlangen, Germany — [3]Department of Physiology, Development and Neuroscience, University of Cambridge, Cambridge, UK

Cell membrane tension influences many important cell functions such as cell division or migration. It is further thought to contribute to transducing mechanical signals, such as the stiffness of the surrounding tissue, into intracellular responses via mechanosensitive ion channels embedded in the membrane. However, how a change in tissue stiffness activates mechanosensitive ion channels in the cell membrane is still not fully understood. In this project, we investigate the effective membrane tension of different cell lines using an optical tweezers setup for membrane tether pulling experiments. We examine cells cultured on glass as well as on polyacrylamide substrates of biologically relevant stiffnesses in order to illuminate how substrate stiffness affects the effective membrane tension. Furthermore, we analyze the correlation between the effective membrane tension and the expression and activity of mechanosensitive ion channels. Our work will contribute to understanding how mechanosensitive ion channels are gated, which may have important implications for drug design in the future.

BP 9.15 Mon 18:00 Poster D

Cellular-Matrix Interactions: The Impact of Cell Density on Fibroblast Contraction in Collagen Matrices — •Christin Heinrichs[1], Lydia Rebehn[1], Hans Kestler[2], Karin Scharffetter-Kochanek[3], and Kay-E Gottschalk[1] — [1]Institute for Experimental Physics, Ulm University, Ulm, Germany — [2]Institute for Medical Systems Biology, Ulm University, Ulm, Germany — [3]Department of Dermatology and Allergology, Ulm University, Ulm, Germany

Fibroblasts, a mesenchymal cell found in connective tissue, maintain the chemical and mechanical homeostasis of the extracellular matrix. To understand the mechanical implications of these cell-matrix interactions we investigate fibroblast contraction in collagen matrices via a 3D printed microscale device[1]. The microscale collagen gel contraction assay simplifies the contraction measurements to one dimension and utilizes a significantly smaller volume of cell-populated gel than a traditional collagen contraction assay. After validating the microscale devices use, we explore the contraction of cell-populated collagen gels with different cell densities reveal potential cooperative effects. Our results underline the need for further investigation into potential collective cell behaviors and the need to explore possible fibroblast transdifferentiation during the experiment.

[1] Zhang, Tianzi, et al. "Investigating fibroblast-induced collagen gel contraction using a dynamic Microscale platform." Frontiers in Bioengineering and Biotechnology, vol. 7, 2019

BP 9.16 Mon 18:00 Poster D

A Pump-Leak model can reproduce the biophysical properties of eukaryotic cell nuclei — •Omar Muñoz[1,2], Abin Biswas[1,3,4], Kyoohyun Kim[1,4], Johen Guck[1,2,4], Vasily Zaburdaev[1,2], and Simone Reber[3,5] — [1]Max-Planck-Zentrum für Physik und Medizin, Erlangen, Germany. — [2]Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen, Germany — [3]Max Planck Institute for Infection Biology, Berlin, Germany — [4]Max Planck Institute for the Science of Light, Erlangen, Germany — [5]University of Applied Sciences Berlin, Berlin, Germany

Biophysical properties of the cell nucleus are important for various cellular processes from migration to stress responses, but largely are still not well understood. One fundamental example is the mass density: we observed that the nuclear mass density consistently displays a lower value than its cytoplasmic counterpart for a wide range of species, which is surprising given that it contains the highly compacted genetic material. To understand the mechanisms behind this, we measured volume and mass density in two systems: growing nuclei reconstituted in Xenopus egg extracts and interphase HeLa cells. We propose a minimal theoretical description using the Pump and Leak model (PLM), which relies on a pressure balance. Based on our experimental results, we incorporate the most relevant contributions to the pressure balance, which we find to be the osmotic pressure and entropic polymer pressure exerted by chromatin. By taking into account relevant biological processes such as nucleocytoplasmic transport and its apparent coupling to chromatin, we are able to reproduce the experimental results.