BP 37: Tissue Mechanics II

Time: Friday 9:30–12:45 Location: BAR/0106

BP 37.1 Fri 9:30 BAR/0106

Active rheology and feedback-controlled stress in a multi-purpose platform for tissue mechanics — •Anna Mukhina[1,2], Till Muenker[1], Mattias Luber[1], Polina Malova[1,2], and Timo Betz[1,2] — [1]Third Institute of Physics - Biophysics, University of Goettingen — [2]Max Planck School Matter to Life

3D tissue engineering offers unique opportunities to study simplified, but accurate models of complex biological systems, where especially force generation, mechanical properties, and active regulation can be addressed. However, most current methods to raise engineered tissues do not allow quantitative characterization of their mechanics without a strong perturbation of these delicate systems.

Here, we present a novel experimental platform to apply well-defined strain to tissues and measure the resulting forces with an optical readout. Tissues are grown between flexible posts, where one post can be actuated by a piezo bending element, and direct optical detection of both posts movement allows for precise force and strain measurement. With this setup, we avoid complex microscopy measurements, can position the system in an incubator, and the rapid readout enables a large variety of experimental protocols. The system can conduct oscillatory rheology, simulate isometric/eccentric contractions, reproduce changes in environmental stiffness during physiological and pathological processes, and adapt stress or strain to mechanical changes of the system. We demonstrate the potential of the developed setup by carrying out oscillatory rheology of engineered skeletal muscles over the course of their maturation, covering three orders of frequency magnitude.

BP 37.2 Fri 9:45 BAR/0106

demonstrating normal tissue sparing with pitz PITZ electron beams in zebrafish embryos — •E Tarakci[1,2,3], C Schulze[2], C Richard[1], M Gross[1], N Aftab[1], A Aksoy[1], Z Amirkhanyan[1], A Chiravuri[1,2], J Good[1], F Hausmann[3], S Khammee[1], Y Komar[1,2,3], M Krasilnikov[1], B Li[1], X Li[1], Z Lotfi[1], G Montoya-Soto[1], F Mueller[1], A Oppelt[1], F Riemer[1], K Suzart[1], I Tinhofer[3], D Villani[1], S Worm[1], D Xu[1], S Zeeshan[1], M Frohme[2], F Stephan[1], S Aminzadeh Gohari[1], and A Grebinyk[1] — [1]Deutsches Elektronen-Synchrotron, DESY, Zeuthen — [2]Technische Hochschule Wildau,Wildau — [3]Charité Universitätsmedizin Berlin, Berlin

Zebrafish (Danio rerio) embryos provide a sensitive model for studying normal tissue responses. This study was conducted within FLASH-lab@PITZ, where PITZ delivers electron beams from conventional to ultra-high dose rates up to 10^15 Gy/s. Wild-type AB embryos at 24 hours post fertilization (hpf) received 10 Gy via conventional X-rays (0.04 Gy/s), low dose rate electrons (LDR, 0.05 Gy/s), or ultra-high dose rate electrons (UHDR, 10^5 Gy/s). At 119 hpf, toxicity was assessed through spinal curvature, pericardial edema, eye diameter, and body length. X-rays and LDR increased toxicity (X-rays: 50% medium, 50% none*mild; LDR: 33% severe, 17% mild, 50% normal). UHDR greatly reduced effects, with no medium or severe toxicity and 42% none and 58% mild changes. These results demonstrate a marked tissue-sparing trend under UHDR conditions and provide early evidence for a FLASH-mediated normal tissue sparing effect.

BP 37.3 Fri 10:00 BAR/0106

Holographic vibration spectroscopy - extracting mechanical properties of adherent cells from their vibrational response — •Eric Schneider[1], Bob Fregin[1], Dominic Mokbel[2], Sebastian Aland[2], and Oliver Otto[1] — [1]Institute of Physics, University of Greifswald, Greifswald, Germany — [2]Institute of Numerical Mathematics and Optimization, TU Bergakademie Freiberg, Freiberg, Germany

The mechanical properties of biological cells are closely linked to their pathophysiological state, and high-throughput quantification is essential for using them as biomarkers in basic and translational research. While microfluidic technologies can characterize suspended cells at rates above 1,000 cells per second, no comparable method exists for adherent cells or tissues. Here, based on preliminary experiments with holographic vibration spectroscopy (HVS), developed in our group, we present a theoretical framework to address this gap. In HVS, adherent cells are harmonically oscillated at defined frequencies and amplitudes, and their deformation and phase shift encode their mechanical properties. To validate this concept, we developed a finite-element simulation framework using the open-source library AMDIS, capable of modeling cellular vibration across a broad parameter space. From these simulations, we derive a protocol to solve the inverse problem and show that viscoelastic properties can be uniquely determined using only the amplitude response at two vibration frequencies. Combined with HVS, this framework will next be used to rapidly and non-invasively quantify the viscoelastic properties of adherent cells and tissues.

BP 37.4 Fri 10:15 BAR/0106

Investigating the dynamics of cellular rearrangements in minimal four-cell clusters — •Agathe Jouneau, Tianyi Cao, and Joachim Rädler — Faculty of Physics and Center for NanoScience, Ludwig-Maximilians-Universität, Munich, Germany

Animal cells assemble into tissues that exhibit diverse mechanical responses, from solid-like to liquid-like states. In solid-like states, tissues can withstand mechanical stress, whereas in liquid-like states, they release stress through cellular rearrangements. Recent evidence suggests that the transition between solid and liquid-like states is central to biological processes such as embryogenesis, wound healing and cancer metastasis. However, the way in which local interactions between the constituent cells control the tissue fluidity remains unclear. The process by which cells exchange neighbors is known as a cell intercalation, or a T1 transition in foam physics terminology. Theoretical models have shown that the height of the energy barrier associated with T1 transitions determines tissue fluidity. In our work, we study the dynamics of T1 transitions in a minimal system of four epithelial cells. We confine the cells onto adhesive micropatterns or in hydrogel microcavities, and use time-lapse microscopy to record the evolution of cell-cell junctions over time. We aim to use this platform to study how perturbations of cell-cell adhesion proteins impact cell rearrangement, as well as to experimentally test existing models for cellular dynamics.

BP 37.5 Fri 10:30 BAR/0106

Collective actuation in solid tissues: Dynamics and mechanics of an oscillating tissue shell during morphogenesis — •Zoë Lange[1], Henrik Jaeschke[1], Lea Möller[1], Mariia Golden[2], Artemiy Golden[2], Marc Pereyra[1], Frederic Strobl[2], Ernst H.K. Stelzer[2], and Franziska Matthäus[1] — [1]Frankfurt Institute for Advanced Studies — [2]Buchmann Institute for Molecular Life Sciences

Morphogenesis relies on coordinated mechanical deformations of embryonic tissues, yet the dynamic material properties that enable these shape changes remain incompletely understood. In the *Tribolium castaneum* embryo, the extraembryonic serosa tissue forms a closed and oscillating epithelial shell, providing a powerful model to study active mechanical processes in vivo. Here, we combine quantitative live imaging with particle image velocimetry, cell-boundary segmentation, cell-boundary tracking, and stress inference methods to characterize the spatiotemporal mechanics of the oscillatory contractions in the tissue shell. We show that the extraembryonic epithelium behaves as an active elastic solid whose global oscillation emerges from synchronizing cellular contraction. By integrating measured deformation with inferred force maps, we identify a cellular program of mechanosensitive remodeling. Our results provide a mechanistic link between active force production at the cellular scale and emergent morphogenetic dynamics at the tissue scale, establishing the *Tribolium* tissue shell as a model system for collective actuation in active elastic materials *in vivo*.

BP 37.6 Fri 10:45 BAR/0106

Plant movement systems enabled by plant hinges: diversity, evolution, form-structure-function relationships and their biomimetic potential — Arooj Sajjad and •Simon Poppinga — Technische Universität Darmstadt, Botanischer Garten, Schnittspahnstraße 2, 64287 Darmstadt, Germany.

Plants are often described as comparatively static systems, yet many species exhibit diverse and mechanically sophisticated forms of movement. In recent decades, such plant movement systems have gained increasing attention due to their remarkable flexibility, versatility, and structural robustness. Plants move in a variety of ways, e.g. to align themselves with sunlight or the earth's gravitational field, to catch

prey, to interact with pollinators, and to adhere to nearby structures in the environment. Plant movements are often enabled by joint-like structures, commonly referred to as plant hinges in the literature. Unlike technical hinges, which allow for rigid body movements and are maintenance-intensive and prone to failure, compliant mechanisms as found in plant movement systems fulfil roles analogous to technical joints, albeit fundamentally differing in form, kinematics, and structure. Interestingly, the hinges in most motile plant structures (e.g. motile sepals in orchids or lever mechanisms in sages) have not been investigated regarding their form-structure-function relationships. In this broad research study, we approach these compliant mechanisms in plants from an engineering perspective on kinematic pairs. Our research also aims to understand convergent mechanisms in plants. One aim is to develop future biomimetic actuator design.

15 min. break

BP 37.7 Fri 11:15 BAR/0106

Understanding tissue mechanics through tumour organoids — •Mathilde G. Lettinga[1], Vaibhav Mahajan[1], Raimund Schlüssler[1], Stefanie Hübner[2,3], Valeria Lozovanu[2,3], Franziska Baenke[2,3,4], Daniel E. Stange[2,3,4], and Anna V. Taubenberger[1] — [1]BIOTEC, CMCB, TU Dresden — [2]VTG, University Hospital Carl Gustav Carus, TU Dresden — [3]DKTK, Heidelberg — [4]NCT/UCC, Dresden

Tumours exhibit altered physical properties that manifest across spatial scales. Compared to healthy tissue, solid tumours are typically stiffer, which can partly be attributed to the extracellular matrix. However, the contributions of the epithelial cancer cells to the emergent tissue properties remain unclear.

Aiming to elucidate the role of cells in tissue mechanics, we investigated the mechanical and morphological properties of patient-derived colorectal liver metastasis organoids. Organoids from different patients varied in morphology, displaying either a large central lumen or a multitude of small lumina. We performed bulk compression with AFM and found that single-luminal organoids are stiffer and more elastic than multi-luminal organoids. Concurrently, Brillouin microscopy in situ showed a higher Brillouin frequency shift for single-luminal organoids, indicating lower compressibility. 3D segmentation revealed more elongated, ordered, homogeneous and smaller nuclei in the single-luminal organoids compared to their multi-luminal counterparts. Thus, our data suggest that the mechanical properties of organoids are coupled to the physical properties of their constituent cells.

BP 37.8 Fri 11:30 BAR/0106

A morphoelastic phase field model predicts buckling instability in tumor growth — Luise Zieger[1], Min Wu[3], John Lowengrub[4], and •Sebastian Aland[1,2] — [1]TU Freiberg — [2]HTW Dresden — [3]Worcester Polytechnic Institute, USA — [4]UC Irvine, USA

It is well known that growing tumors generate and respond to stress in their local environment. On the one hand, local cell proliferation and apoptosis lead to complex strain patterns in the tissue. On the other hand, tissue re-arrangements can relax the resulting mechanical shear stresses and make the tissue more fluid-like. To predict the outcomes of these nonlinear visco-elastic interactions, we introduce the framework of morphoelasticity to phase field modeling of a growing tumor embedded in a surrounding host tissue. Coupling this continuum system to diffusible growth-promoting nutrient, our simulations identify a symmetry-breaking instability in 2D and 3D driven by two primary mechanisms: (i) elastic buckling instability generated by tangential stresses along the tumor-host interface and (ii) instabilities generated by local imbalances between cell divisions and cell death. Further, tissue fluidity and compressibility can lead to changes in tumor topologies. Our modeling framework provides a robust methodology for investigating how tissue mechanics and growth factor signaling influence the progression and invasive potential of solid tumors.

BP 37.9 Fri 11:45 BAR/0106

Orientational lineage memory and mechanical ordering during diffusion-limited growth — •Ilias-Marios Sarris[1], Ramin Golestanian[1,2], and Philip Bittihn[1] — [1]MPI for Dynamics and Self-Organization, Göttingen, Germany — [2]Rudolf Peierls Centre for Theoretical Physics, University of Oxford, United Kingdom

Growth and shape formation in crowded multicellular assemblies arise from the interplay of chemical gradients, single-cell expansion, and mechanical interactions. Using a particle-based model that resolves nutrient fields and cellular orientations with tunable lineage memory, we study how orientational order emerges in expanding fronts whose morphology is set by nutrient limitation. We find a transition in nematic order controlled by front morphology: under strong orientation inheritance, both thin active layers (fingering fronts) and thick active layers (flat fronts) produce strong alignment, while intermediate cases are less ordered. Velocity, reorientation, and stress statistics reveal a crossover from inheritance-dominated to mechanically driven alignment that progressively overrides lineage memory. As a result, orientational memory yields a fitness advantage only in the diffusion-limited, memory-dominated regime, elucidating how nutrient supply and mechanics jointly shape self-organization during growth.

BP 37.10 Fri 12:00 BAR/0106

Feedback-controlled epithelial mechanics: emergent soft elasticity and active yielding — •Fridtjof Brauns[1,2], Pengyu Yu[3,4], and M. Cristina Marchetti[3] — [1]MPI-PKS, Dresden, Germany — [2]KITP, Santa Barbara, USA — [3]University of California, Santa Barbara, USA — [4]Tsinghua University, Beijing, China

Biological tissues exhibit distinct mechanical and rheological behaviors during morphogenesis. While much is known about tissue phase transitions controlled by structural order and cell mechanics, key questions regarding how tissue-scale nematic order emerges from cell-scale processes and influences tissue rheology remain unclear. Here, we develop a minimal vertex model that incorporates a coupling between active forces generated by cytoskeletal fibers and their alignment with local elastic stress in solid epithelial tissues. We show that this feedback loop induces an isotropic–nematic transition, leading to an ordered solid state that exhibits soft elasticity. Further increasing activity drives collective self-yielding, leading to tissue flows that are correlated across the entire system. This remarkable state, that we dub plastic nematic solid, is uniquely suited to facilitate active tissue remodeling during morphogenesis. It fundamentally differs from the well-studied fluid regime where macroscopic elastic stresses vanish and the velocity correlation length remains finite, controlled by activity. Altogether, our results reveal a rich spectrum of tissue states jointly governed by activity and passive cell deformability, with important implications for understanding tissue mechanics and morphogenesis.

BP 37.11 Fri 12:15 BAR/0106

Neuromechanics of peristalsis — •Sifan Yin[1], Suraj Shankar[2], and Lakshminarayanan Mahadevan[3] — [1]MPI-PKS, Dresden, Germany — [2]University of Michigan, Ann Arbor, MI, US — [3]Harvard University, Cambridge, MA, US

The peristalsis of cylindrical-shaped organisms or organs is driven by the propagation of rhythmic waves of contraction and relaxation along the tube wall. These waves are generated by coupled interactions of neural control, mechanotransduction, and active muscular contraction. Here, we propose a minimal neuromechanical model for spontaneously coordinated peristaltic waves by locally coupling the neuro-muscular dynamics to the mechanics of an active elastic tube, such as the Nematostella body, the gastro-intestinal tract, and the ureters. We analyze our model using a combination of analytical and numerical methods to investigate the nucleation, propagation and extinction of pulse, and the transitions between disordered twitching and coordinated traveling waves. Our theory naturally elucidates how the interactions among mechanics and neural activities can give rise to coordinated peristaltic motion without any center pattern generator (CPG). This work can supplement ways to robustly design robotics with neural feedback and help to understand early peristaltic wave generation before CPG formation, especially in early embryonic development.

BP 37.12 Fri 12:30 BAR/0106

Muscle growth by sarcomere divisions — Clement Rodier[1], Ian D. Estabrook[2,3], Frank Schnorrer[1], and •Benjamin M. Friedrich[2] — [1]IBDM, Marseilles, France — [2]EXC Physics of Life, TU Dresden, Germany — [3]EMBL, Heidelberg, Germany

The sarcomere is the elementary contractile unit of muscles. Sarcomeres are organized into highly regular periodic chains termed myofibrils, which span the millimeter-length of muscle cells. During development, new sarcomeres are added to mechanically tensed myofibrils as muscle cells increase in length. Yet, how muscles add new sarcomeres to facilitate muscle growth remained elusive. Using live imaging and high-throughput image analysis of the Drosophila flight muscle, we identified a new mechanism of tension-driven sarcomere addition where individual sarcomeres divide along the myofibril tension axis into daughter sarcomeres. Thereby, new sarcomeres can be inserted

into contractile myofibrils without compromising their mechanical integrity. A similar mechanism may apply in vertebrate muscle development and regeneration.

[1] Rodier et al. Sci. Adv. 11(28), 2025