CPP 2: Mechanics and Dynamics of 3D Tissues (joint focus session BP/CPP, organized by BP)

Time: Monday 9:30–13:00 Location: SCH A251

Invited Talk CPP 2.1 Mon 9:30 SCH A251

Cilia-based transport networks — •Eberhard Bodenschatz — MPI für Dynamik und Selbstorganisation , Am Fassberg 17, 37077 Goettingen

Cerebrospinal fluid conveys many physiologically important signaling factors through the ventricular cavities of the brain. We investigated the transport of cerebrospinal fluid in the third ventricle of the mouse brain and discovered a highly organized pattern of cilia modules, which collectively give rise to a network of fluid flows that allows for precise transport within this ventricle. Our work suggests that ciliated epithelia can generate and maintain complex, spatiotemporally regulated flow networks. I shall also show results on how to assemble artificial cilia and cilia carpets. This work is in collaboration with Regina Faubel, Gregor Eichele, Christian Westendorf, Azam Gholami, Isabella Guido, Yong Wang, Albert Bae and Marco Tarantola. Support by the Max Planck Society and the BMBF within the MaxSynBio initiative is gratefully acknowledged.

CPP 2.2 Mon 10:00 SCH A251

Quantitative structure-function relationships in 3D tissues — •Janna Nawroth — Emulate Inc., Boston, MA, USA

Biological tissues are characterized by an organ-specific three-dimensional, multiscale organization of cells and extracellular matrix components. This organization gives rise to organ-specific functions and dysfunctions. Tissue engineering attempts to recapitulate these structure-function relationships in vitro to provide models of disease, drug toxicity, and patient-specific responses. One major challenge is to identify and implement quantitative metrics that capture the most relevant structure-function relationships to serve for both quality control and experimental readout of the engineered tissue. Here, I present engineering and analysis strategies for recapitulating and quantifying the cellular organization and mechanical functions in engineered cardiac muscle and in ciliated epithelia, with a particular emphasis on organ-on-chip technology.

CPP 2.3 Mon 10:30 SCH A251

***In vivo* quantification of spatially-varying mechanical properties in developing tissues** — •Friedhelm Serwane[1,2], Alessandro Mongera[1], Payam Rowghanian[1], David Kealhofer[1], Adam Lucio[1], Zachary Hockenbery[1], and Otger Campas[1] — [1]University of California, Santa Barbara, USA — [2]Max Planck Institute for Medical Research, Heidelberg, Germany

We present a technique that allows quantitative spatiotemporal measurements of mechanical properties *in vivo* using biocompatible ferrofluid droplets as local mechanical actuators [1].

The mechanical properties of the cellular microenvironment and their spatiotemporal variations play a central role in controlling cell behavior, including cell differentiation. However, no direct *in vivo* and *in situ* measurement of mechanical properties within developing 3D tissues has been performed yet.

Using our technique we show that vertebrate body elongation entails spatially varying tissue mechanics along the anteroposterior axis. Specifically, we find that the zebrafish tailbud is viscoelastic: elastic below a few seconds and fluid after just one minute. Furthermore, it displays decreasing stiffness and increasing fluidity towards its posterior elongating region.

This method opens the door to study mechanobiology *in vivo*, both in embryogenesis and in disease processes, including cancer.

[1] F. Serwane, A. Mongera, P. Rowghanian, D. Kealhofer, A. Lucio, Z. Hockenbery, O. Campàs. Nature Methods, in press (2016)

CPP 2.4 Mon 10:45 SCH A251

Mechanical spectroscopy of retina explants at the protein level employing nanostructured scaffolds — •Mareike Zink[1] and S. G. Mayr[2] — [1]Soft Matter Physics Division, University of Leipzig, Leipzig, Germany — [2]Leibniz Institute for Surface Modification (IOM), Leipzig, Germany & Division of Surface Physics, Department of Physics and Earth Sciences, University of Leipzig, Germany

The mechanical properties of the retina play a crucial role in function and diseases of the eye. Here we present that nanostructured TiO2 substrates can be employed as vibrating reed to investigate the mechanical properties of adult mammalian retinae at the nanometer. Within a self-designed mechanical spectroscopy setup, the reed with the retina on top is excited to perform free damped oscillations. The detected oscillation parameters represent a fingerprint of the frequency-dependent mechanical tissue properties that are derived in combination with sandwich beam analysis and finite element calculations. We found that the Young's modulus of the retina is of the order of a few GPa, much higher than values obtained from experiments in which tissue response is investigated on micrometer length scales. In our study, polymers and proteins on the photoreceptor side of the retina in contact with the nanostructured reed are stretched and compressed during vibration of the underlying scaffold and the acting intramolecular forces are probed at the protein level. To this end, our mechanical spectroscopy approach offers new perspectives in studying mechanical response of individual proteins within the tissue for investigating tissue mechanics, diseases and the effect of drugs.

15 min break

CPP 2.5 Mon 11:15 SCH A251

A simulation study on 3D muscle movement: eigen-frequency and force-coupling to the skeleton change with muscle activity — Daniel F B Haeufle, Daniel Wirtz, •Kevin Kraschewski, Syn Schmitt, and Oliver Röhrle — Stuttgart Research Center for Simulation Technology (SimTech), University of Stuttgart, Germany

The muscles in the human body are soft materials coupled flexibly to the rather rigid bones. Due to this flexible coupling, muscles move relative to the bones during movement. The resulting coupling forces of these so-called wobbling masses depend on the neural stimulation of the muscle tissue. It is experimentally very difficult to study the relation between muscle stimulation and coupling forces. Therefore, we developed a 3D continuum-mechanical model of a muscle-tendon complex considering muscle stimulation, elasticity, viscosity, fiber orientation, and tendon stiffness. This model predicts the interaction forces in response to external oscillatory excitations in dependence on excitation frequency and muscle stimulation level. With this approach, the functional role of wobbling masses in human movement, e.g., energy dissipation and force reduction during the impact in human running, can be studied in more detail.

CPP 2.6 Mon 11:45 SCH A251

Electromechanical Turbulence in the Heart — •Jan Christoph and Stefan Luther — Max Planck Institute for Dynamics and Self-Organization, Göttingen, Germany

The self-organizing pattern forming mechanisms underlying highly life-threatening cardiac fibrillation are still insufficiently understood. High-speed fluorescence imaging provides highly detailed visualizations of the spatio-temporal electrophysiological activity of the heart. During ventricular fibrillation, these visualizations depict complex spatio-temporal electrical patterns including rotating vortices or spiral waves on the heart's surface. However, with limited penetration depths of fluorescence imaging the optically mapped surface dynamics reflect only the superficial projection of three-dimensional wave phenomena that evolve within the depths of the cardiac muscle.

We combined fluorescence imaging with ultrasound to study the coupled electrical and mechanical activity of the fibrillating heart on its surface as well as within the heart wall. We found that during fibrillation electrical activity patterns and elasto-mechanical deformations are highly correlated producing co-localized patterns of electrical and mechanical activation. Specifically, we found that electrical spiral wave rotors can be accompanied by rotational elasto-mechanical patterns, which like fingerprints of vortex activity occur as a characteristic feature within the deformations of the fibrillating muscle. Our data highlights the importance of studying the mechanics and dynamics of 3D cardiac tissues to obtain a better understanding of cardiac arrhythmias and to conceptualize novel diagnostic and therapeutical strategies.

CPP 2.7 Mon 12:00 SCH A251

Local rules for robust global transport in liver networks —

•Jens Karschau[1], Andre Scholich[2], Marius Asal[1], Hidenori Nonaka[3], Hernan Morales-Navarrete[3], Fabian S Miranda[3], Kirstin Meyer[3], Yannis Kalaidzidis[3], Marino Zerial[3], Frank Jülicher[2], and Benjamin M Friedrich[1] — [1]cfaed / TU Dresden — [2]MPI PKS, Dresden — [3]MPI CBG, Dresden

The liver represents a chemical factory that is characterised by intertwined transport networks for toxins and metabolites. Each hepatocyte cell of the liver tissue interacts with two space-filling networks: bile canaliculi and sinusoids which transport bile and blood, respectively. How these networks establish their distinct architecture to supply all hepatocytes, and dynamically adapt to time-varying load as well as to local perturbations remains elusive.

Here, we elucidate design principles of liver tissue structure and self-organisation based on experimental high-resolution imaging data from mice. First, we characterise and quantify liver tissue with tools from liquid-crystal theory that show lobule level patterns of aligned cell polarity and local network anisotropy. Second, we study a simplified flow model to understand the relationship between the spatial structure of the network and robust transport properties. Third, we compare our flow simulations in reconstructed bile canaliculi networks and simulated self-organised networks. Thereby, we establish a connection between local network geometry and properties of global fluid transport, linking tissue structure with function.

CPP 2.8 Mon 12:15 SCH A251

Jamming and liquidity in 3D cancer cell aggregates — •Linda Oswald[1], Steffen Grosser[1], Jürgen Lippoldt[1], Steve Pawlizak[1], Anatol Fritsch[2], and Josef Käs[1] — [1]University of Leipzig — [2]MPI CBG Dresden

Traditionally, tissues are treated as simple liquids, which holds for example for embryonic tissue. However, recent experiments have shown that this picture is insufficient for other tissue types, suggesting possible transitions to solid-like behavior induced by cellular jamming. The coarse-grained self-propelled Voronoi (SPV) model predicts such a transition depending on cell shape which is thought to arise from an interplay of cell-cell adhesion and cortical tension. We observe non-liquid behavior in 3D breast cancer spheroids of varying metastatic potential and correlate single cell shapes, single cell dynamics and collective dynamic behavior of fusion and segregation experiments via the SPV model.

CPP 2.9 Mon 12:30 SCH A251

Type IV pili govern the internal dynamics of *Neisseria gonorrhoeae* microcolonies. — •Wolfram Pönisch[1], Christoph Weber[2], Khaled Alzurqa[3], Hadi Nasrollahi[3], Kelly Eckenrode[3], Nicolas Biais[3], and Zaburdaev Vasily[1] — [1]Max Planck Institut für Physik Komplexer Systeme, Dresden — [2]Harvard University, Cambridge — [3]Brooklyn College, New York

An important step in the evolution of biofilms is the formation of microcolonies, agglomerates of cells that can consists of several thousands of cells. For many pathogenic bacteria, i.e. *N. gonorrhoeae* or *P. aeruginosa*, the attractive cell-cell-interactions required for microcolonies to form are mediated by micron-long and thin appendages, the called type IV pili. We are interested in the pili-mediated dynamics of individual bacteria within microcolonies and how they affect the properties of the agglomerates. In experiments, we observe a gradient of motility of cells of *N. gonorrhoeae*, depending on their position within a colony. We will present a computational model of cells interacting via individual pili. It allows us to model microcolonies on biologically relevant temporal and spatial scales and is able to reproduce the differential motility of cells within a colony. Furthermore, it enables us to study quantities that are not yet accessible by experiments, e.g. the cell density within a colony, the pili-mediated cell forces and force fluctuations and the internal structure of the colonies. Finally, we will present how the assembly and morphology of microcolonies is affected by the pili properties, particularly for mixtures of cell populations characterized by mutations of their pilus apparatus.

CPP 2.10 Mon 12:45 SCH A251

Growth Dynamics of Biofilms — •Benedikt Sabass[1,2], Jing Yan[2], Howard A. Stone[2], and Ned S. Wingreen[2] — [1]Forschungszentrum Jülich — [2]Princeton University

Bacteria can form tight communities that are called biofilms. Although biofilms are ubiquitous and ecologically important, little is known about the physics of biofilm growth. Here, we focus on rod-shaped V. cholerae bacteria that form hemispherical biofilms when growing on a surface. Using high-resolution microscopy data, we measure cell density, cell orientation, and shape evolution of the biofilm. We quantitatively explain the density and cell orientation inside the biofilm by minimization of elastic energies. The evolution of the whole biofilm shape is governed by apparent viscous relaxation. We find that the shape parameters of biofilms follow rather simple, generic scaling laws.