

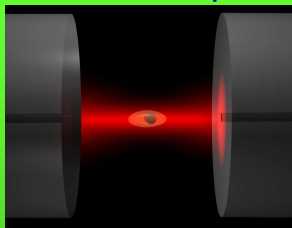
Soft Matters: Photonics and Mechanics in Biomedicine

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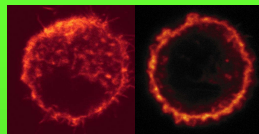
BSS
Biological
and Soft
Systems

Most of what we know in Physics has been derived from experience with the inanimate world. One remaining challenge represents the transfer of these concepts to living objects such as cells, tissues, and entire organisms, where it is not certain if they are appropriate or even relevant. We investigate the mechanical and optical properties of living cells and tissues using novel photonic tools to test their relevance and importance for biological function. Our ultimate goal is the transfer of our findings to medical application in the fields of improved diagnosis of diseases and novel approaches in regenerative medicine with an impact on clinical practice.

The Optical Stretcher

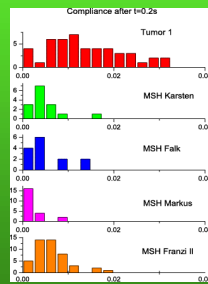


Schematic of the optical stretcher. Two counter-propagating NIR laser beams deform a cell.



Difference in the cytoskeleton of a healthy (left) and a cancerous cell (right). The cancerous cell is more deformable.

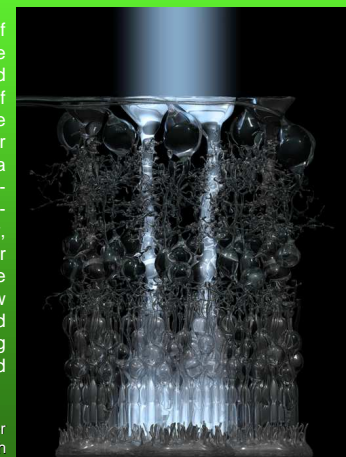
The optical stretcher is a novel laser tool that can be used to trap and deform individual biological cells. The forces arise from the momentum transfer of light to the surface. The deformation can be used to study the cytoskeleton, which is an internal polymer gel resisting the external forces. Changes in the cytoskeleton are diagnostic for pathological changes and can be detected with the optical stretcher. Ultimately, we are developing a label-free, high-throughput cell analysis method for cancer diagnosis and stem cell sorting.



The deformability of cells from cancerous oral lesions (red) is increased compared to healthy controls. This can be used for screening for oral cancer.

Cells as Optical Fibres

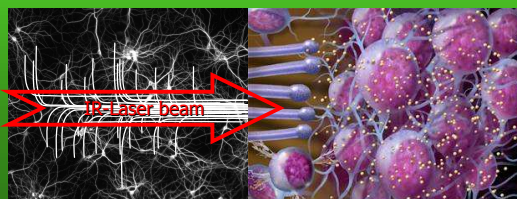
Quite unlike smooth cylindrical optical glass fibers, most animal cells are irregular in shape and inhomogeneous in their optical properties. However, using a modified dual-beam laser trap, we found that individual Müller cells, which are elongated glial cells in the vertebrate retina, act as optical fibres. Confocal microscopy images of retinal tissue were consistent with this property also *in situ*. Specific geometrical and optical properties of Müller cells enable efficient collection and low-scattering transport of light through an otherwise scattering tissue. Their parallel array in the retina is reminiscent of fiber-optic plates used for low-distortion image transfer, thus suggesting a similar function in vertebrate vision. This assigns a new function to glial cells and solves a long-standing problem of the inverted retina.



Schematic of two Müller cells funneling light through the retina.

Nerve Regeneration

The long standing paradigm that neurons in the CNS cannot regenerate is gone (after 3500 years). While most research to date is biochemical, there are also physical aspects that need to be considered. We are developing tools to investigate axonal growth and to stimulate and direct it in certain directions. Specifically, we are using IR laser beams to guide axonal growth into mechanical barriers, such as glial scars present after neurological trauma to see whether those pose mechanical barriers to nerve regeneration. We are also investigating the importance of mechanical cues for normal differentiation and axonal pathfinding during development.

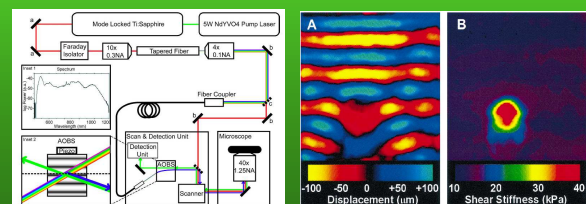


A laser beam directs the growth of axons in 3D neuronal cultures.

Axon growth (from left) is stopped by a glial scar as a mechanical barrier.

Novel Imaging Tools

We have successfully combined a white-light laser source with scanning confocal and multiphoton microscopy. This allows to work with any dye, rather than being limited by specific filter sets. This also opens the possibility for the development of novel imaging tools such as coherent-anti Raman spectroscopy (CARS) imaging or absorption microscopy in combination with 3D scanning. We are also interested in establishing quantitative imaging modalities of the mechanical properties of tissues. This includes ultrasound imaging of mechanical properties of tissue samples (glial scars, retinal layers) *in vitro* and NMR elastography of mechanical properties *in vivo* (brain, spinal cord).



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