Introduction to Neuromechanics

Summer 2016
Tue/Thu/Fri 8:30-10:00, 10:30-12:00
Seminarraum 00.044
Lehrstuhl für Technische Mechanik
Egerlandstrasse 5

Silvia Budday (silvia.budday@ltm.uni-erlangen.de)
Ellen Kuhl (ekuhl@stanford.edu)

Our brain is not only our softest, but also our least well-understood organ. Floating in the cerebrospinal fluid, embedded in the skull, it is almost perfectly isolated from its mechanical environment. Not surprisingly, most brain research focuses on the electrical rather than the mechanical characteristics of brain tissue. Recent studies suggest though, that the mechanical environment plays an important role in modulating brain function. Neuromechanics has traditionally focused on the extremely fast time scales associated with dynamic phenomena on the order of milliseconds. The prototype example is traumatic brain injury where extreme loading rates cause intracranial damage associated with a temporary or permanent loss of function. Neurodevelopment, on the contrary, falls into the slow time scales associated with quasi-static phenomena on the order of months. A typical example is cortical folding, where compressive forces between gray and white matter induce surface buckling. To understand the role of mechanics in neuroanatomy and neuromorphology, we begin this course by dissecting mammalian brains and correlate our observations to neurophysiology. We discuss morphological abnormalities including lissencephaly and polymicrogyria and illustrate their morphological similarities with neurological disorders including schizophrenia and autism. Then, we address the role of mechanics during brachycephaly, plagiocephaly, tumor growth, and hydrocephalus. Last, we explore the mechanics of traumatic brain injury with special applications to shaken baby syndrome.

Syllabus

Focus Neuroanatomy / Dissection

Tue 28/06	08:30-10:00	Introduction to Brain Anatomy
Thu 30/06	10:30-12:00	Dissecting Brains - Kinematics
Fri 01/07	08:30-10:00	Brain Anatomy - Group Presentations

Focus Neuromechanics / Elasticity

Tue 28/06	10:30-12:00	Introduction to Brain Mechanics
Thu 30/06	08:30-10:00	Brain Mechanics in 1D – Elasticity of Neurons
Fri 01/07	10:30-12:00	Brain Mechanics in 3D – Elasticity of the Brain

Focus Neurodevelopment / Growth

Tue 05/07	08:30-10:00	Brain Growth in 1D –Growing Axons
Tue 05/07	10:30-12:00	Brain Growth in 3D – Brain Development

Focus Neurosurgery / Swelling

Thu 07/07	08:30-10:00	Brain Fluid Mechanics – Hydrocephalus
Thu 07/07	10:30-12:00	Brain-Skull Interaction – Craniosynostosis and Tumors

Focus Neuropathologies / Damage

Fri 08/07	08:30-10:00	Brain Dynamics in 1D - Diffuse Axonal Injury
Fri 08/07	10:30-12:00	Brain Dynamics in 3D - Traumatic Brain Injury

Focus Neuroanatomy / Dissection

Tue 28/06 **Introduction to Brain Anatomy**
08:30-10:00 Understanding the basics of brain anatomy
Your brain by the numbers
Important features for mechanical analysis
Brain imaging in vivo – Magnetic resonance imaging

Thu 30/06 **Dissecting Brains - Kinematics**
10:30-12:00 Understanding brain anatomy through dissection
Coronal, transverse, and sagittal sections
Frontal, parietal, occipital, and temporal lobes
Ventricles and cerebrospinal fluid

Fri 01/07 **Brain Anatomy** - **Group Presentations**
08:30-10:00 Understanding the brain as a bi-material
Gray and white matter
Cortical thickness, gyri and sulci
Gyral wavelength and gyrification indices

Focus Neuromechanics / Elasticity

Tue 28/06 **Introduction to Brain Mechanics**
10:30-12:00 Understanding the basics of brain mechanics
Slow time scales – Brain development
Fast time scales – Traumatic brain injury
Role of mechanics in classical pathologies

Thu 30/06 **Brain Mechanics in 1D – Elasticity of Neurons**
08:30-10:00 Understanding the brain as a collection of neurons
Introduction to 1D kinematics, equilibrium, constitutive equations
Notion of deformation, stretch, strain, stress, stiffness
Brain imaging in vivo – Diffusion Tensor MRI

Fri 01/07 **Brain Mechanics in 3D – Elasticity of the Brain**
10:30-12:00 Understanding the brain as a multiscale material
Introduction to 3D kinematics, equilibrium, constitutive equations
Notion of deformation, deformation gradient, strain, stress
Brain testing ex vivo - Compression, shear, indentation
Brain testing in vivo – Magnetic Resonance Elastography

Focus Neurodevelopment / Growth

Tue 05/07 **Brain Growth in 1D – Growing Axons**
08:30-10:00 Understanding axons as living matter
Axonal tension
Chronic axon elongation
Axon testing ex vivo – Towed growth

Tue 05/07 **Brain Growth in 3D – Brain Development**
10:30-12:00 Understanding instabilities
Competition between compression and bending
Critical wavelength, cortical thickness, stiffness, and growth
Physiological and pathological development
Lissencephaly and polymicrogyria, Craniosynostosis

Focus Neurosurgery / Swelling

Thu 07/07 **Brain Fluid Mechanics – Hydrocephalus**
08:30-10:00 Understanding the cerebrospinal fluid
Abnormal accumulation of cerebrospinal fluid
Increase in intracranial pressure and swelling
Decompressive Craniectomy

Thu 07/07 **Brain-Skull Interaction – Craniosynostosis and Tumors**
10:30-12:00 Understanding changes to the mechanical environment
Opening the brain - Craniosynostosis
Removing part of the brain - Brain Tumors
BBC Documentary - Neurosurgeons at Oxford Hospital

Focus Neuropathologies / Damage

Fri 08/07 **Brain Dynamics in 1D - Diffuse Axonal Injury**
08:30-10:00 Understanding axonal damage and rupture
Notion of stretch rate, strain rate, stress
Introduction to damage mechanics
Diffuse Axonal Injury

Fri 08/07 **Brain Dynamics in 3D - Traumatic Brain Injury**
10:30-12:00 Understanding brain damage and injury
Introduction to damage mechanics
Notion of velocity, velocity gradient, strain rate, stress
Shaken baby syndrome, traffic accidents, blast impact, sport injuries
Chronic Traumatic Encephalopathy