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**
**8:30-10:00**
**Brain Growth in 1D – Growing Axons**
- Understanding axons as living matter
- Axonal tension
- Chronic axon elongation
- Axon testing ex vivo – Towed growth

**Tue 05/07**
**10:30-12:00**
**Brain Growth in 3D – Brain Development**
- 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**
**8:30-10:00**
**Brain Fluid Mechanics – Hydrocephalus**
- Understanding the cerebrospinal fluid
- Abnormal accumulation of cerebrospinal fluid
- Increase in intracranial pressure and swelling
- Decompressive Craniectomy

**Thu 07/07**
**10:30-12:00**
**Brain-Skull Interaction – Craniosynostosis and Tumors**
- 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**
**8:30-10:00**
**Brain Dynamics in 1D - Diffuse Axonal Injury**
- Understanding axonal damage and rupture
- Notion of stretch rate, strain rate, stress
- Introduction to damage mechanics
- Diffuse Axonal Injury

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