ME 239 – Mechanics of the Cell

Tue/Thu 3:15-4:30pm, 320-105
Ellen Kuhl, ekuhl@stanford.edu, Durand 217, office hours Wed 2pm

Cells are the fundamental building blocks of life. The understanding of their characteristic biological features, their motility, their biochemistry and their interaction with the environment is crucial when cells are to be applied, modified or engineered in health care and modern medical therapies. This class focuses on the mechanical aspects of the cell which can be two fold: On the one hand, cell biology and biochemistry influence the mechanical properties of the cell. On the other hand the mechanical environment, load, pressure, stress, or strain can influence the cell's shape and integrity, and eventually its biology and biochemistry. In the first part of this class, we will discuss how cell properties can be measured experimentally and how they can be characterized in the form of equations. Concepts of energy and entropy will be elaborated for different structural units of the cell: biopolymers, i.e., microtubules, actin, and intermediate filaments and biomembranes, i.e., the lipid bi-layer that forms the cell membrane. Computational simulation tools will be introduced to explain and understand cell behavior in silico. In the second part, we address aspects of mechanotransduction which are part of active research in cell mechanics. We discuss different aspects of how cells sense loads and how signals are transmitted within the cell and through the extracellular matrix.

Grading

Homework	30 %	three homework assignments, 10% each
Midterm	30 %	closed book, closed notes, one single page cheat sheet
Final Project	20 %	oral presentation, graded by the class
Final Project	20%	written project essay, grated by instructor

Tue 03/30 **Introduction I - Cell biology**
- Overview of the cell
- Biochemistry
- Biopolymers
- Biomembranes

Thu 04/01 **Introduction II - Cytoskeletal biology**
- Cytoskeletal composition and structure
- Role of cell mechanics in regulating cell structure and function
- Stem cells

Tue 04/06 **Introduction III - Structural mechanics**
- Equilibrium - stress
- Kinematics - strain
- Material behavior – stress strain relation

In plane and out of plane deformation
Energy and entropy

Thu 04/08 **Biopolymers I – Energy**
Structural mechanics of biopolymers
Tension, bending, and buckling

Tue 04/13 **Biopolymers II – Entropy**
Introduction to statistical mechanics
Freely jointed chain model
Worm like chain model

Thu 04/15 **Biopolymers III – Polymerization**
Polymerization kinetics
Actin, tubulin, and microtubules
Treadmilling
Amoeba

Tue 04/20 **Cytoskeletal mechanics I**
Fiber bundle model
Filopodia

Thu 04/22 **Cytoskeletal mechanics II**
Chain network models
Red blood cells

Tue 04/27 **Cytoskeletal mechanics III**
Tensegrity models
Generic eukaryotic cells

Thu 04/29 **Biomembranes I**
Pipette aspiration
Law of Laplace
Liquid drop model
White blood cells and cartilage cells

Tue 05/04 **Biomembranes II**
Lipid bilayers
Soap bubbles
Cell membranes

Thu 05/06 **Biomembranes III**
Mechanics of biomembranes
Tension, shear, and bending

Tue 05/11 **Mechanotransduction I**
Inter- and intracellular signaling
Ion channels
Bone cells

Thu 05/13 **Mechanotransduction II**
Electrical signaling
Nerve cells

Tue 05/18 **Midterm**

Thu 05/20 **Mechanotransduction III**
Excitation contraction
Skeletal muscle cells and heart cells

Tue 05/25 **Cell biology – Movies and discussion**
Oral presentations evaluated by the class

Thu 05/27 **Final projects I**
Oral presentations evaluated by the class

Tue 06/01 **Final projects II**
Oral presentations evaluated by the class

Tue 06/01 **Final projects due**
Written project essays due

Suggested reading

[1] Phillips R, Kondev J, Theriot J: Physical Biology of the Cell, Garland Science, Cambridge, 2008

[2] Boal D: Mechanics of the Cell, Cambridge University Press, Cambridge, 2002

[3] Howard J: Mechanics of Motor Proteins and the Cytoskeleton, Sinauer Associates, Sunderland, 2001

[4] Alberts B et al.: Molecular Biology of the Cell, Garland Science, Taylor & Francis, New York, 2002