BIOEN 440/ ME 445: Intro to Biomechanics

Instructors: Saniel Lim, Jonathan Realmuto, Nikita Taparia
Teaching Assistant: Corey Pew
Time/ Place: 11:30-1:20 PM Tuesday/ Thursday in Smith Hall 102
Office Hours: 2-4 pm Tuesday, 2-3 pm Thursday (Green Room C) or 11-12 pm Monday

Course Design and Objectives

This course will have three major divisions taught by each instructor based on their expertise. We will give an introduction to biomechanics on three different length scales – cell, tissue, and musculoskeletal. Within this course you will do the following:

1. Apply fundamental principles from mathematics, physics, chemistry, computing, engineering, and biology to solve biomedical and biotechnological problems.
2. Derive design principles from nature and apply them to solve biomedical problems and to develop bioengineering technologies.
3. Work in multidisciplinary teams and communicate problems and their solutions effectively with physicians, scientists, and other engineers.
4. Take ethical and social issues into consideration in solving bioengineering problems.
5. Continue to develop technical knowledge, awareness, and leadership abilities to address domestic or global issues in human health

Prerequisites

We expect students to have taken calculus, differential equations, linear algebra, mechanics of materials, and physics. Because this is a cross-listed class, we will assume students have a high school biology background. We will be giving a knowledge probe on the first day, which should give insight on the level of the class.

Required Text

There is no required text. Lecture notes for each topic are provided. Required reading [paper discussions] and optional reading is also included.

Structure of the Class

Grading

The design behind the grading is to primarily promote student interactions and discussion, team-based learning, and self-reflection. Here is the basic breakdown.

9 HW (100 pts) - 40%

- The homework is meant to challenge you and test your ability to use your previous knowledge of engineering and apply it towards biomechanics problems.

In class work/participation - 10%

- The lectures will have in class work to break up the 2 hour slot and give you the opportunity to work through problems/project. ***Thus, attendance is required.*** Imagine each week as 1%!

1 Group Project (100pts) - 50%

- Oral Project Proposal (15%), Oral Project Update (15%), Final Written Report (35%), Oral Final Presentation (35%), Team Assessment (Multiplier)

Course Policy

PLAGIARISM will result in a ZERO. If you are not familiar with the academic policy on plagiarism, get familiar via website online. All assignments must be turned in on time except if you have instructor permission – let us know if there is a health or family emergency.

Access and Accommodations. If you experience barriers based on a disability or temporary health condition, please seek a meeting with DRS to discuss and address them. If you have already established accommodations with DRS, please communicate your approved accommodations to your instructor at your earliest convenience so we can discuss your needs in this course.

Late Homework Policy: Homework is due at the beginning of class. If you are going out of town, please scan it and send it to us by the same time. If you hand it in by 11:59 pm the day homework is due, it is 10% off. Otherwise, late homework will result in zero credit.

Tentative Schedule

Module 1: Cell Mechanics (Nikita)

Lecture 1: Cell Mechanics as a Framework

1. Describe the basic role of a cell.
2. Describe the mechanics of a cell.
3. Review important concepts in mechanics.

Lecture 2: Mechanics of Cellular Polymers

1. Describe the molecular structure of 3 important cytoskeleton polymers: microfilaments, microtubules, and intermediate filaments.
2. Model the polymerization kinetics in microfilaments and microtubules.
3. Apply mechanics fundamentals to understand the fundamental biopolymers.
4. Describe 3 different polymer models: Ideal Chain, Freely Joined Chain, and Wormlike Chain

Lecture 3: Polymer Networks and Cytoskeleton

1. Define mechanics of specific cytoskeletal architectures found in vivo.
    a. Define the fiber bundle model and apply it to a filopodia formation
    b. Define the chain network model and apply it to a red blood cell.
    c. Define the tensegrity model and apply it to generic eukaryotic cells.

Lecture 4: Mechanics of Cell Membrane

1. Define the cell membrane's structural organization.
2. Describe the mechanics of a membrane – tension, shear and bending – red blood cells
3. Describe experimental and modeling approaches in the study of biomembranes.
    a. Micropipette Aspiration with respect to white blood cells and cartilage cells.
    b. Atomic Force Microscopy– estimate the elastic moduli

Lecture 5: Adhesion, Migration, and Contraction

1. Describe the biology and mechanics of adhesion.
    a. Optical tweezer and micropipette aspiration to measure platelet receptor-ligand force
2. Describe the biology and mechanics of migration.
    a. Traction Force Microscopy
3. Describe the biology and mechanics of contraction.
4. Hill Model, Frank-Sterling Equation, Power-Stroke Model --- Guest Lecture

Lecture 6: Mechanotransduction & Intracellular Signaling

1. Describe the four stages of mechanotransduction – example cells) skin and hair cells
2. Describe electrical signaling and electrophysiology with respect to nerve cells.
3. Describe electrochemical signaling and excitation contraction with respect to skeletal and cardiac muscle cells --- Guest Lecture

Module 2: Tissue Mechanics (Saniel)

Lecture 1: Structure and function of tissue

1. Describe the tissue types and structures
2. Describe the brief function of its tissue type
3. Identify the components of connective tissue; extracellular matrix (ECM)

Lecture 2: Mechanical properties of tissue

1. Describe stress-strain responses of various tissues
2. Describe physiological behaviors and structural considerations of tissue
    a. skin, tendon, muscle, blood vessels
3. Identify physical characteristics of tissue based on testing data

Lecture 3: Mathematical models of tissue properties

1. Review basic elasticity and viscoelasticity
2. Describe elastic, viscoelastic, and hyperelastic models
3. Describe assumptions, advantages, and disadvantages of modeling

Lecture 4: Mechanical property testing methods

1. Describe various mechanical property testing methods
2. Describe the difference among in-vivo, in-vitro, and ex-vivo testings

Lecture 5: Elastography techniques

1. Describe the clinical need of elastography
2. Introduce various imaging modalities for elastography
3. Describe the current status and future roles of elastography

Lecture 6: Shear wave elastography

1. Describe the relationship between speed of sound and stiffness
2. Describe analytical modeling and testing methods
3. Introduce the applications of shear wave elastography

Module 3: Musculoskeletal Mechanics (Jonathan)

Lecture 1: Neuromusculoskeletal System

1. Describe the functional role of the nervous system, muscle system and skeletal system in human movement.
2. Describe the interactions between nerves, muscles and the skeleton.
3. Describe "motor units" and their function.
4. Model and simulate the dynamic response of motor units.

Lecture 2: Measuring and Describing Motion: Kinematics

1. Identify and apply standardized notation and language to describe human movement.
2. Describe motion capture for gait analysis.
3. Describe basic EMG principles used in motion analysis.
4. Apply signal processing to movement signals.
5. Describe other kinematic acquisition techniques.
6. Apply 3D rigid body kinematics to human movement.
7. Identify local joint coordinate frames and convert local coordinates into the global coordinates.

Lecture 3: Forces and Torques: Kinetics

1. Identify and describe forces involved in human locomotion.
2. Apply laws of motion to human movement.
3. Describe the difference between the center of mass and center of pressure.
4. Apply inverse dynamics to solve for resulting joint forces given kinematic data.
5. Describe the inverted pendulum model for walking.

Lecture 4: Mechanical Work, Energy, and Power

1. Apply law of conservation of energy to human movement.
2. Describe the difference between internal and external work.
3. Describe the difference between positive and negative muscle work.
4. Describe joint mechanical power.
5. Calculate internal and external work.
6. Understand and describe energy storage and transfer, and power balance.

Lecture 5: Movement Synergies and Adaptability

1. Describe muscle warm-up effect, soreness and damage.
2. Describe the support moment synergy.
3. Describe dynamic balancing during walking.

Lecture 6: Movement Models and Simulations, Artificial Joints and Limbs

1. Describe the mechanism of passive dynamic walkers.
2. Understand limitations of models and simulations.
3. Describe the principles behind artificial joints.
4. Describe the difference between series- and parallel- elastic actuators.
5. Describe basic control theory of lower limb prosthetics.