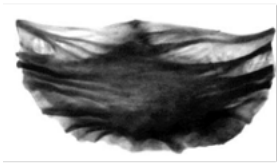
Biomechanics of Tissues, Scaffolds, and Cells

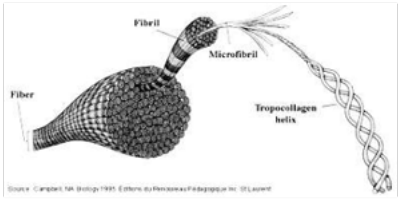
Michael S. Sacks

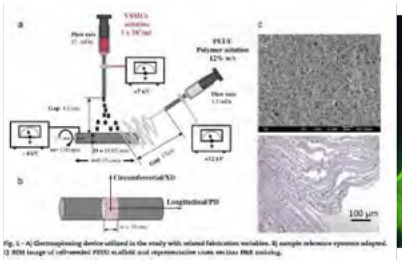
James T. Willerson Center for Cardiovascular Modeling and Simulation
Oden Institute for Computational Engineering Sciences ◇ Department of Biomedical Engineering

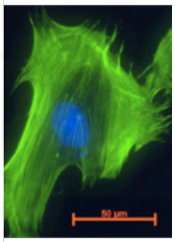
The University of Texas at Austin

Fall 2021









1. Overview

Biomechanics includes the study of the whole body; it's organs and systems, the tissues that make up the organs, their constituent cells, cell organelles, and the large complex molecules that form the basis of all living systems. Biosolid mechanics covers the complex mechanical behaviors of these structures, with a focus on modeling how they respond under loading. This response includes not only stress and deformation, but also mechano-biological responses of living systems. In addition to the science of biomechanics, there is a huge area of applications-driven research that includes understanding of many pathophysiological processes, medical device design and failure analysis. A great example of this is the development of novel biomaterials for tissue and device replacement. This will be a *project-based* course organized around major application areas to provide context to the theory and applications we will be covering. This should help the student better understand why we do what we do and stimulate interest in the materials covered. During the semester we will introduce the necessary mathematical, mechanics, and biological fundamentals using applications and examples extensively. Each course section will include problems in biomedical research and medical devices.

2. General Information

2.1. Time/Place

Class: 9:30-11:00 am T, Th, Room ETC 2.132
Zoom link: Fa21 - 2-CELL/TISSUE/SCAFFOLD BIOMCH (15395)
https://utexas.zoom.us/j/91220060309

Meeting ID: 912 2006 0309 One tap mobile +13462487799,,91220060309# US (Houston) +16699006833,,912
US (San Jose)

2.2. Office hours:

2.2.1. Primary office hours

M,T,W,Th 11 am - 12 noon
In-person only: Room 5.236 POB

2.2.2. Alternate office hours

M,T,W,Th 5 pm - 6 pm
In-person only: Room 5.236 POB

2.3. Contact hours:

2.5 hours/week lecture 4 hours/week office hours

2.4. Email:

I will always be available via email, but please only use the CANVAS email service only. This allows me to store the emails just in case, and to avoid missing them or having them captured in a SPAM folder.

2.5. BSBME

This is a senior level elective BSBME course.

2.6. Prerequisites

2.6.1. BME majors

Required:

1. BME 313L Intro to Numerical Methods in BME
2. The materials covered in this course will be particularly dependent on this particular pre-req. I will have a short review of these materials at the beginning of the course and through the semester as needed.
3. BME 335 Engr. Probability and Statistics
4. BME 344 Biomechanics
5. BME 353 Transport Phenomena in Living Systems
6. BME 365R Quantitative Engineering Physiology I
7. BME 365S Quantitative Engineering Physiology II

Highly recommended:

1. BME 352 Engineering Biomaterials
2. M340L Matrices and Matrix Calculus

2.6.2. non-BME majors

For the non-BME student, a background in strength of materials, matrix algebra, and programming is strongly recommended.

2.7. Software

The homework for this course will be problem based, with a focus on both mathematical and data-driven assignments. I will be using the Python programming language in the Jupiter Lab Notebook environment. This will allow for a single consistent platform to perform all assignments. It also fun to use (honest). For all symbolic work, I strongly recommend using Mathematica or Sympy (Python). If you are rusty or have not used these packages for a while, I recommend starting a few weeks before class and familiarizing yourself with them. Mathematica is still the best mathematical notation and derivation software, but has a steep learning curve. Sympy is workable and will do most things you need within the python environment. Supplemental use of other packages such as MATLAB will be allowed, but only in a supportive manner. Please check with Dr. Sacks for any specific questions.

3. Texts

3.1. Main Texts

"Mechanics of Natural and Synthetic Biological Structures" by Michael S. Sacks

3.2. Supplimental texts

1. "Solid Mechanics" by Kelly.
2. Suppplemental materiasl supplied as a PDF.

4. Assignments and Grading

There will be no in-class or take-home exams. The final grade will be based on homeworks, which will be assigned approximately every week.

5. Attendance

See COVID-19 section. In general, Dr. Sacks will be work with individual situations to help the student deal with any personal issues that arise during the semester.

6. POLICY ON DISABILITIES

"The University of Texas at Austin provides upon request appropriate academic adjustments for qualified students with disabilities. For more information, contact the Office of the Dean of Students at 471-6259, 471-4241 TDD or the College of Engineering Director of Students with Disabilities at 471-4382."

7. POLICY ON CHEATING

Students who violate University rules on scholastic dishonesty are subject to disciplinary penalties, including the possibility of failure in the course and dismissal from the University. Since dishonesty harms the individual, fellow students, and the integrity of the University, policies on scholastic dishonesty will be strictly enforced. Also, as it is expected that each student will rigorously follow the UT ethical behavior rules (see http://www.engr.utexas.edu/ethics), all projects will be considered the sole work by an individual student. Any evidence for plagiary will result in a failing grade for that assignment, and potentially for the entire course.

8. Cell Phone and Laptop Policy

Laptops and tablets are only allowed to be ON if lecture notes are being typed. The Instructor reserves the right to check these notes in such case. Cell phones must be muted and out of sight.

9. COVID 19

The following is our current plans for the COVID 19 for the first 3.5 weeks.

1. All lectures will be recorded.
2. All lectures will be live streamed.
3. In-person attendance is not required but optional.
4. Masks are strongly encouraged but are not required at this time.
5. Office hours will be held online until further notice.
6. Zoom cloud recordings will be made straight to the cloud.

10. ABET Student Outcomes and BME/BioE Program Criteria addressed by the course

Student Outcomes taught in this course

SO1 - YES
SO2 - YES
SO3 - NO
SO4 - NO
SO5 - NO
SO6 - YES
SO7 - YES

BME/BioE Program Criteria included in this course.

A - YES
B - YES
C - YES
D - YES

COURSE SCHEDULE

Part I - Overview

Lecture 1: Thursday—August 26, 2021:
Topic(s):

1. Course overview and philosophy
2. Review of recent trends in biomechanics research

Reference Materials:

1. Lecture 1 slides
2. Chapter 1 in 'Mechanics of Natural and Synthetic Biological Structures'

Part II - Mechanics of Hard Tissues

Lecture 2: Tuesday—August 31, 2021:
Topic(s):

1. Bone Structure and Function.

Reference Materials:

1. Lecture 2 and 3 slides
2. Chapter 2 in 'Mechanics of Natural and Synthetic Biological Structures'

Lecture 3: Thursday—September 2, 2021:
Topic(s):

1. Bone Structure and Function.

Reference Materials:

1. Lecture 2 and 3 slides
2. Chapter 2 in 'Mechanics of Natural and Synthetic Biological Structures'

Lecture 4: Tuesday—September 7, 2021:
Topic(s):

1. Mathematical review of vectors and matrices

Reference Materials:

1. Chapter 11 in 'Mechanics of Natural and Synthetic Biological Structures'

Lecture 5: Thursday—September 9, 2021:
Topic(s):

1. Stress and strain in 2D and 3D

Reference Materials:

1. Lecture slides
2. Chapter 3 in 'Mechanics of Natural and Synthetic Biological Structures'

Lecture 6: Tuesday—September 14, 2021:
Topic(s):

1. Stress and strain in 2D and 3D
2. Coordinate transformations

Reference Materials:

1. Lecture slides
2. Chapters 3 and 11.1-11.5 in 'Mechanics of Natural and Synthetic Biological Structures'

Lecture 7: Thursday—September 16, 2021:
Topic(s):

1. An Introduction to Generalized Linear Elasticity

Reference Materials:

1. Lecture slides
2. Chapter 4 in 'Mechanics of Natural and Synthetic Biological Structures'

Lecture 8: Tuesday—September 21, 2021:
Topic(s):

1. An Introduction to Generalized Linear Elasticity

Reference Materials:

1. Lecture slides
2. Chapter 4 in 'Mechanics of Natural and Synthetic Biological Structures'

Lecture 9: Thursday—September 23, 2021:
Topic(s):

1. Bone Elasticity

Reference Materials:

1. Lecture slides
2. Chapter 5 in 'Mechanics of Natural and Synthetic Biological Structures'

Lecture 10: Tuesday—September 28, 2021:
Topic(s):

1. Bone Elasticity

Reference Materials:

1. Lecture slides
2. Chapter 5 in 'Mechanics of Natural and Synthetic Biological Structures'
3. Additional papers

Lecture 11: Thursday—September 30, 2021:
Topic(s):

1. APPLICATION: Hard tissue studies 1 - The hip implant

Reference Materials:

1. Lecture slides
2. Reference materials

Lecture 12: Tuesday—October 5, 2021:
Topic(s):

1. APPLICATION: Hard tissue studies 2 - Bone growth and remodeling

Reference Materials:

1. Lecture slides
2. Reference papers

Part III - Soft Tissues and Elastomeric Biomaterials

Lecture 13: Thursday—October 7, 2021:
Topic(s):

1. Soft Tissue Structure and Function

Reference Materials:

1. Lecture slides
2. Chapter 6 in 'Mechanics of Natural and Synthetic Biological Structures'

Lecture 14: Tuesday—October 12, 2021:
Topic(s):

1. Soft Tissue Structure and Function

Reference Materials:

1. Lecture slides
2. Chapter 6 in 'Mechanics of Natural and Synthetic Biological Structures'

Lecture 15: Thursday—October 14, 2021:
Topic(s):

1. Stress and strain in finite deformation

Reference Materials:

1. Chapter 7 in 'Mechanics of Natural and Synthetic Biological Structures'

Lecture 16: Tuesday—October 19, 2021:
Topic(s):

1. Stress and strain in finite deformation

Reference Materials:

1. Chapter 7 in 'Mechanics of Natural and Synthetic Biological Structures'

Lecture 17: Thursday—October 21, 2021:
Topic(s):

1. Models of soft and tissues

Reference Materials:

1. Chapter 8 in 'Mechanics of Natural and Synthetic Biological Structures'

Lecture 18: Tuesday—October 26, 2021:
Topic(s):

1. Models of soft tissues

Reference Materials:

1. Chapter 8 in 'Mechanics of Natural and Synthetic Biological Structures'

Lecture 19: Thursday—October 28, 2021:
Topic(s):

1. APPLICATION: Modeling myocardium and heart valve tissues

Reference Materials:

1. Selected publications.

Lecture 20: Tuesday—November 2, 2021:
Topic(s):

1. Structural models for soft tissues

Reference Materials:

1. Chapter 8 in 'Mechanics of Natural and Synthetic Biological Structures'

Lecture 21: Thursday—November 4, 2021:
Topic(s):

1. Structural models for soft tissues

Reference Materials:

1. Chapter 8 in 'Mechanics of Natural and Synthetic Biological Structures'

Lecture 22: Tuesday—November 9, 2021:
Topic(s):

1. APPLICATIONS: How structural models are applied to soft tissues - I

Reference Materials:

1. Key papers in Supplemental Materials

Lecture 23: Thursday—November 11, 2021:
Topic(s):

1. APPLICATIONS: How structural models are applied to soft tissues - II

Reference Materials:

1. Key papers in Supplemental Materials

Lecture 24: Tuesday—November 16, 2021:
Topic(s):

1. APPLICATIONS: How to implement structural models numerically using Python.

Reference Materials:

1. Posted python code examples.

Part IV - Cell mechanics

Lecture 25: Thursday—November 18, 2021:
Topic(s):

1. A review of cell biology and function.

Reference Materials:

1. Key papers

Lecture 26: Tuesday—November 23, 2021:
Topic(s):

1. Basic modeling of cell mechanics.

Reference Materials:

1. Key papers.

Lecture 27: Thursday—November 30, 2021:
Topic(s):

1. What is viscoelasticity?

Reference Materials:

1. Chapter 9 in 'Mechanics of Natural and Synthetic Biological Structures'

Lecture 28: Thursday—December 2, 2021:
Topic(s):

1. How to model cell viscoelasticity

Reference Materials:

1. Key papers.