Biomechanics of Tissues, Scaffolds, and Cells

Michael S. Sacks

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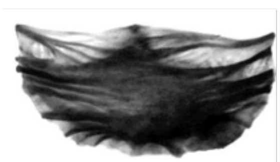
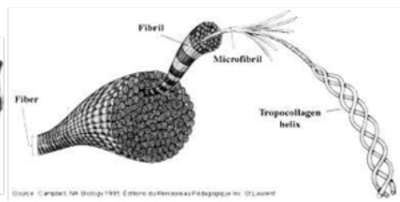
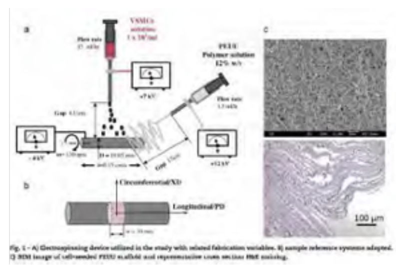
The University of Texas at Austin

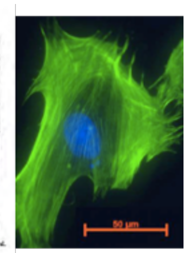
Course Unique numbers: BME 384T:15770, CSE 397:65550, ME 385J:19620, BME 373:15635, COE 379L:15085

Fall 2022









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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. Instructor

Dr. Michael S. Sacks
W.A. "Tex" Moncrief, Jr. Simulation-Based Engineering and Sciences Chair
Director Willerson Center for Cardiovascular Modeling and Simulation
Professor of Biomedical Engineering

Office: Room 5.236 POB
Email: msacks@oden.utexas.edu
Phone: 512-272-7773
Note: 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.

2.2. Time/Place

Class: 11:00 am - 12:15 pm T, Th, Room GDC 4.304
In-person only

Office hours: M,T,W,Th 4:30 pm-5:30 pm, Room 5.236 POB
In-person only

2.3. TAs

While there will be no formal TAs for this course, Robin Tuscher and Natalie Simonian will be available to answer software questions via email (again using CANVAS only). One on one meetings can also be setup on an individual basis in the unlikely event Dr. Sacks cannot help you out.

2.4. Lecture mode and recordings

This course will be offered strictly in-person. However, all lectures will be recorded and made available on CANVAS. Recordings should be available within 24 hours.

2.5. Contact hours:

2.5 hours/week lecture 4 hours/week office hours

2.6. BSBME

This is a senior level elective BSBME course.

2.7. Prerequisites

2.7.1. 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

2.7.2. non-BME majors

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

3. TEXTS

3.1. Main Text

"Mechanics of Natural and Synthetic Biological Structures" by Michael S. Sacks, including supplemental materials.

This book is under contract with Springer-Nature, so if you have any suggestions on what you would like to see, please email Dr. Sacks!

3.2. Supplemental texts

"Solid Mechanics" by Kelly. This is a undergraduate level text with additional examples, and is very good for general background.

3.3. Homeworks and Software

Homework. Homework assignments will be assigned every 1-2 weeks and will be graded within 1-2 weeks, all using CANVAS. All submissions are required to follow the following format:

1. Be in PDF format only, as a single file.
2. Clearly state assignment number, your name, and date, and include page numbers.
3. Clearly label each question number and clearly format your answers. You are welcome to create different parts of the assignment using different software, as long as the final result is in PDF format and merged into a single file.
4. If you have to scan material, please be sure the quality is good and the entire page is clearly readable, with no shadows, etc. In general, scanned material is strongly discouraged (you should not need to use it).
5. Please be sure to check the PDF for any errors BEFORE you submit. Again, be sure to upload only a single PDF file.
6. Please do not upload any code files. Note that the JLNB PDF will contain all code.

All submission must be done through CANVAS only. All graded materials and grade information will also be available on CANVAS.

Homeworks will be focused on the following:

1. Factual knowledge of an application.
2. Mathematical derivations and solutions of basic problems.
3. Data-driven modeling of biological and synthetic structures.

Required software. For this course I will be exclusively using the Python programming language in the Jupiter Lab Notebook (JLN) environment (https://jupyter.org). This will allow for a single consistent platform to perform all assignments. It also fun to use (honestly). We will utilize the following formats/packages

1. For all text based work, you can do this by using Word.
2. Another (recommended!) option is to use a JLN with LATEX to create nice text, especially if you need to use equations.
3. For all symbolic work we will use SyMPY (https://www.sympy.org/en/index.html). It is generally pretty easy to use and will also format answers quite nicely.
4. I recommend use of MATPLOTLIB (https://matplotlib.org). There are plenty of other related Python based graphics utilities you can use.
5. For all numerical work (e.g. integration) when working with actual data, we will use NUMPY (https://numpy.org) and SciPy (https://scipy.org).
6. JLNB natively supports LATEX. See https://www.overleaf.com/learn for quick and easy tutorials and examples.

All these packages are available for any platform (Windows, MAC, Linux) using ANACONDA at https://www.anaconda.com/. ANACONDA makes installation/updating very easy.

Phase-in. If you are rusty or have not used these packages before - **DON'T PANIC!**. I recommend starting to familiarize yourself with them asap. You will find the time invested will be well rewarded. While older commercial packages, such as MATLAB and Mathematica, will continue to be used outside the University environment. Python/JLNB is more current, has a huge family of libraries, and its FREE. If you need more time to get up to speed, supplemental use of other packages or work by hand will be allowed, but only for the first few weeks.
Please check with Dr. Sacks for any specific questions.

4. GRADING

There will be no in-class or take-home exams. The final grade will be based on homeworks only.

5. ATTENDANCE

Attendance is mandatory. As problems always arise, Dr. Sacks will work with individual situations to help the student deal with any personal issues during the semester. However, it is the student's responsibility to contact Dr. Sacks to make arrangements ASAP.

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 LAPTOPS

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

As of today, the current UT policy is for in-class attendance. I am also recording all lectures which will be made available via CANVAS. Masks are optional.

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 and Mathematical Foundations

Lecture 1: Tuesday—August 23, 2022:

Topic(s):

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

Reference Materials:

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

Lecture 2: Thursday—August 25, 2022:

Topic(s):

1. Mathematical review of vectors and matrices

Reference Materials:

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

Lecture 3: Tuesday—August 30, 2022:

Topic(s):

1. Software overview.

Reference Materials:

1. Lecture slides
2. Appendix A2 in 'Mechanics of Natural and Synthetic Biological Structures'
3. Your laptop (to try the demos).
4. JLN examples from CANVAS.

Part II - Mechanics of Hard Tissues

Lecture 4: Thursday—September 1, 2022:

Topic(s):

1. Bone Structure and Function.

Reference Materials:

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

Lecture 5: Tuesday—September 6, 2022:

Topic(s):

1. Bone Structure and Function.

Reference Materials:

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

Lecture 6: Thursday—September 8, 2022:
Topic(s):

1. Stress and strain in 2D and 3D

Reference Materials:

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

Lecture 7: Tuesday—September 13, 2022:
Topic(s):

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

Reference Materials:

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

Lecture 8: Thursday—September 15, 2022:
Topic(s):

1. An Introduction to Generalized Linear Elasticity

Reference Materials:

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

Lecture 9: Tuesday—September 20, 2022:
Topic(s):

1. An Introduction to Generalized Linear Elasticity

Reference Materials:

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

Lecture 10: Thursday—September 22, 2022:
Topic(s):

1. Anisotropic Elastic Behavior of Bone

Reference Materials:

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

Lecture 11: Tuesday—September 27, 2021:
Topic(s):

1. Anisotropic Elastic Behavior of Bone

Reference Materials:

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

3. Additional papers

Lecture 12: Thursday—September 29, 2022:
Topic(s):

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

Reference Materials:

1. Lecture slides
2. Reference materials

Lecture 13: Tuesday—October 4, 2022:
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 14: Thursday—October 6, 2022:
Topic(s):

1. Soft Tissue Structure and Function

Reference Materials:

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

Lecture 15: Tuesday—October 11, 2022:
Topic(s):

1. Soft Tissue Structure and Function

Reference Materials:

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

Lecture 16: Thursday—October 13, 2022:
Topic(s):

1. Kinematics, Strain, and Stress in Finite Deformation

Reference Materials:

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

Lecture 17: Tuesday—October 18, 2022:
Topic(s):

1. Kinematics, Strain, and Stress in Finite Deformation

Reference Materials:

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

Lecture 18: Thursday—October 20, 2022:
Topic(s):

1. Hyperelastic Constitutive Models I: Isotropic Solids

Reference Materials:

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

Lecture 19: Tuesday—October 25, 2022:
Topic(s):

1. Hyperelastic Constitutive Models II: Anisotropic models for soft tissues: The Fung Model

Reference Materials:

1. Chapter 10 in 'Mechanics of Natural and Synthetic Biological Structures'

Lecture 20: Thursday—October 27, 2022:
Topic(s):

1. Hyperelastic Constitutive Models II: Anisotropic models for soft tissues: Pseudo-Invariant Approaches.

Reference Materials:

1. Chapter 10 in 'Mechanics of Natural and Synthetic Biological Structures'

Lecture 21: Tuesday—November 1, 2022:
Topic(s):

1. APPLICATION: Modeling heart valve and myocardial tissues.

Reference Materials:

1. Chapter 11 in 'Mechanics of Natural and Synthetic Biological Structures'
2. Key papers in Supplemental Materials

Lecture 22: Thursday—November 3, 2021:
Topic(s):

1. Elastomeric biomaterials

Reference Materials:

1. Chapter 11 in 'Mechanics of Natural and Synthetic Biological Structures'
2. Key papers in Supplemental Materials

Lecture 23: Tuesday—November 8, 2021:
Topic(s):

1. Elastomeric biomaterials

Reference Materials:

1. Chapter 11 in 'Mechanics of Natural and Synthetic Biological Structures'
2. Key papers in Supplemental Materials

Part IV - Viscoelasticity

Lecture 24: Thursday—November 10, 2022:
Topic(s):

1. Basic concepts in viscoelasticity

Reference Materials:

1. Chapter 14 in 'Mechanics of Natural and Synthetic Biological Structures'

Lecture 25: Tuesday—November 15, 2022:
Topic(s):

1. The Boltzmann superposition principal in viscoelasticity

Reference Materials:

1. Chapter 14 in 'Mechanics of Natural and Synthetic Biological Structures'

Part V - Cell mechanics

Lecture 26: Thursday—November 17, 2022:
Topic(s):

1. A review of mechanobiology of cell function.

Reference Materials:

1. Chapter 13 in 'Mechanics of Natural and Synthetic Biological Structures'

Lecture 27: Tuesday—November 29, 2022:
Topic(s):

1. Modeling the mechanics of cells.

Reference Materials:

1. Chapter 13 in 'Mechanics of Natural and Synthetic Biological Structures'

Lecture 28: Thursday—December 1, 2022:
Topic(s):

1. APPLICATION: The valve interstitial cell

Reference Materials:

1. Chapter 13 in 'Mechanics of Natural and Synthetic Biological Structures'