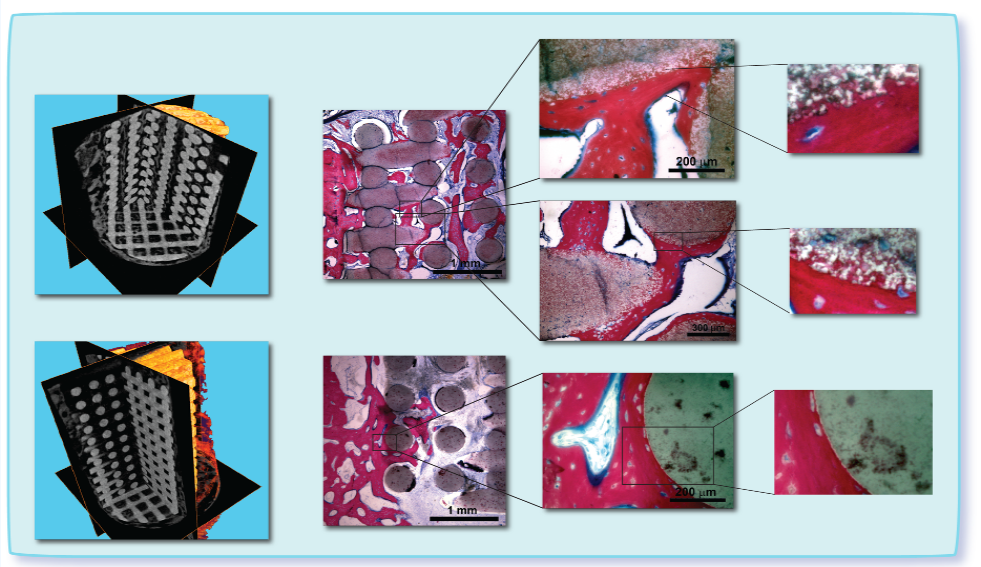
ME 482 Experimental Tissue Mechanics

Professor A. Wagoner Johnson

Monday, 8/22/16



See Piazza for all handouts and some lecture notes
piazza.com/illinois/fall2016/me482/home

NOTE: many of the images used in the notes are selected based on their visual value, and are cited. The sources are not necessarily scholarly, and therefore these or ones like them might not be appropriate for use as references in your projects.

Instructor:	Prof. A. J. Wagoner Johnson	(ajwj@illinois.edu)	128 MEB
Teaching Assistant:	Zach Berent	(berent2@illinois.edu)	238 MEB
Office Hours:	Will post on Piazza (piazza.com/illinois/fall2016/me482)		
Text:	No required text. Handouts will be posted on Piazza and will include sections from relevant books. I will also post slides/notes/handouts, which often contain figures that I cannot draw, etc. They will *not* be a complete set of notes.		

Course Description (course calendar)

The course focuses on microstructure-property relationships of tissue in the musculoskeletal system including bone, tendon, ligament, and cartilage. The **goal** is to understand how the tissue structure and composition relate to mechanical properties of healthy and diseased tissue. Emphasis will be on *experimental* tissue mechanics. There is a major laboratory component (more info to come). You will work very hard, but students generally do very well!

Incomplete List of Learning Objectives

Tissue Structure (bone, cartilage, tendon, ligament, muscle) and function

- Describe the mechanical and biological functions of each tissue.
- Know the composition each of the tissues, and, in particular, the relative compositions.
  - This is important for understanding the relative mechanical properties and function.
- Describe and sketch the hierarchical structure of each of the tissues and know the length-scales of the structures.
- Know the cell types and their roles in each of the tissues.

Mechanical Properties

- Know the magnitude of the basic mechanical properties (strength, stiffness, at a minimum) of each of the tissues and relate them to the function of that tissue.
- Understand how the composition and structure give different mechanical properties.
- Describe why the tissues are viscoelastic and understand viscoelasticity.
- Understand the mathematics and physical interpretations of some simple viscoelastic models.
- Relate the basic property values to other engineering materials.
- Know and understand the origin of anisotropic of properties.
- Understand the relationship between diseased or damaged tissue and its properties.

Technical Communication

- Be able to conduct effective literature searches. This is very important to the class project (separate handout).
- Be able to critically assess the literature and demonstrate your ability to do so through the paper reviews, required for the project, as well as for the major written and oral parts of the project.
- Demonstrate an improvement in technical writing and presentation skills throughout the semester, in particular if I or the TA makes specific suggestions.

Grading

1. *Homework (15%: 4 bigger ones including calculations/problems and several smaller ones)*
2. *Laboratory assignments and reports (30%: 4@ 7% ea. + 2% for active participation)*
   See separate handout with details.
3. *Exams (2 midterms @ 10% ea.* **Week of Oct. 12th and Dec. 5th***)*
   Primarily bone mechanics; Primarily cartilage and tendon/ligament mechanics
4. *Project (35%)*
   See separate handout with details.

90-100, A; 80-90, B; 70-80, C; 60-70, D, 0-60, F, +/- largely assigned by participation or demonstrated improvements. Grades will not be curved down, but may be uniformly curved up at the discretion of the professor.

Homework (15%)
There will be approximately four homework assignments that focus on calculations, solving more involved problems, and using software (excel, matlab, statistics software, indentation simulation software etc.) We will guide you in their use. In particular, there will be a hands-on lecture devoted to statistical analysis using OriginPro (also very useful for labs) and a MatLab tutorial will be provided for those who are not familiar, but would like to use it. There will be several other shorter assignments focusing on finding information and discussions; these do not involve calculations or require the use of software.

Lab assignments and reports (30%: 4 reports @7% ea. + 2% participation) Website: me482uiuc2016.wordpress.com
There are four labs, each with a pre-lab assignment and a lab report. Participation and attendance are essential and required. Details will be in a separate handout and discussed in class.

Project Paper Reviews (Project is 35%, Paper Reviews are 20% of Project)
Each student will submit 2 written reviews of a technical journal article. *NOTE: 4 HR STUDENTS WILL SUBMIT 3.* Details on the format and requirements will be provided separately. As a general guideline, reviews should not be more than 5 pages double-spaced. Review articles are *not* appropriate targets for paper reviews. This is *not* a group activity; it is an individual effort. *Use papers for your reviews that are important to your project. You cannot review the same paper as your project partner.*

Exams (2 @10% ea. Week of Oct. 12th and Dec. 5th)
Two exams will be given roughly covering the first half and second half of the course. There is no final exam. The final exam time will be used for project presentations and ALL STUDENTS MUST ATTEND. This year I am experimenting with oral exams, 10 minutes long, conversation style. I will discuss this in detail in class and will provide the list of questions at least two weeks in advance.

Piazza (piazza.com/illinois/fall2016/me482)
We use Piazza, a platform designed to efficiently manage Q&A and class resources. Students can post questions and collaborate Wikipedia-style; instructors answer questions, endorse answers, and edit or delete any posted content. I encourage you to post questions on Piazza rather than emailing me or the TA. This way *everyone* has access to questions. It is likely you are not the only one with the question!

Expectations on technical writing and presentation
I do not expect that everyone will be expert on technical writing and presentation, but I do expect that there will be no spelling or typographical errors and that there will be a noticeable improvement between the beginning and end of the semester. If I give particular suggestions for improvement, I expect effort in those areas.

General Notes and Expectations

- Lab assignments/reports and homeworks that can be done in pairs or groups **will be indicated**. If not noted, then these should be individual efforts.
- You can work with a partner for the class project, but **not** the associated paper reviews.
- **Attend class and participate!** Because there is no textbook, you have to rely on handouts, notes from class, and class discussions. If you miss class, please get the information from your colleagues. If you have specific questions related to an absence, please post on Piazza and/or contact me. There is a lot going on in the class between assignments, labs, etc. It is highly recommended that you attend class.
- Ask questions! If I do not know the answer, I will try to find out.
- Respect everyone and in particular their opinions and contributions.
- Communicate with me and with teammates if something is not going as you expected.
- Observe the rules of academic integrity. See www.admin.uiuc.edu/policy/code/article_1/a1_1-402.html.

Written Assignments and Plagiarism

- All written assignments must be submitted through Compass as a "plagiarism" check and will use this as a "learning tool" to discuss what is appropriate and what is not. This is VERY important.
- It is ultimately your responsibility to understand the nuances of plagiarism. See www.admin.uiuc.edu/policy/code/article_1/a1_1-402.html part d.

Student Code & Academic Integrity

"All students are responsible to refrain from infractions of academic integrity, conduct that may lead to suspicion of such infractions, and conduct that aids others in such infractions."

"I did not know" is not an excuse.

The following are academic integrity infractions:

- Cheating - using or attempting to use unauthorized materials
- Plagiarism - representing the words, work, or ideas of another as your own
- Fabrication - falsification or invention of any information, including citations
- Facilitating infractions of academic integrity - helping or attempting to help another commit infraction
- Bribes, Favors, and Threats - actions intended to affect a grade or evaluation
- Academic Interference - tampering, altering or destroying educational material or depriving someone else of access to that material

(source http://www.provost.illinois.edu/academicintegrity/students.html)

  - ***Violators will be caught*** – we check!!

- Easily fail course or worse!
- All infractions are documented in campus-wide FAIR database

ME482 Lab Schedule (subject to change, updated 8/22) Fall 2016

- *Lab materials are available at: me482uiuc2016.wordpress.com*
- *Course calendar found at: course calendar*
- *Locations for lab activities that are not in MEB will be announced on Piazza: piazza.com/illinois/fall2016/me482*
- *Sign-ups for labs that require sign-up will be first-come, first-served and available 2 weeks in advance on Piazza.*
- *Some groups will test outside normal lab sessions.*

Week 1 **Aug. 22 – Aug. 26**	**Friday, August 26** Lecture: Regular Class Lecture (@218MEB) 11:00AM – 11:50AM
Week 2 **Aug. 29 – Sep. 2**	**Friday, September 2** Lecture: Regular Class Lecture(@218MEB) 11:[illegible] – 11:50AM
Week 3 **Sep. 5 – Sep. 9**	**Friday, September 9** *Lecture: Technical Writing (@218MEB)* [illegible] – 11:50AM *Lecture Lab 1: Intro to Unconfined Compression Tests* [illegible]:00AM – 11:50AM
Week 4 **Sep. 12 – Sep. 16**	**Friday, Septem[illegible]** *Sample Prep Lab 1: Soft Tissue Di[illegible]g Knee (@113 MEB)* ***Lab section sign-up: ~60 min. slot*** **Lab 1 Pre-Lab Due**
Week 5 **Sep. 19 – Sep. 23**	**F[illegible]ber 23** *Testing Lab 1: Unconfined C[illegible]esting of Porcine Articular Cartilage (@IGB)* ***[illegible]sign-up: ~30 min. slot***
Week 6 **Sep. 26 – Sep. 30**	**[illegible]riday, September 30** *Origin Demo[illegible]ysis and Significance (@EWS Lab)* 11:00AM – 11:50AM
Week 7 **Oct. 3 – Oct. 7**	**Friday, October 7** *Le[illegible]*[illegible]lass Lecture (@218MEB) 11:00AM – 11:50AM **Lab 1 Report Due**
Week 8 **Oct. 10 – Oct. 14** **Exam I**	******Monday, October 10***(@218MEB)*** Lecture Lab 2: Second Generation (SHG) Imaging (Prof. Toussaint) 11:00AM–11:50AM ***Friday, October 14*** *Testing Lab 2: Fourier-Transform SHG Imaging of Porcine Tendon (@IGB)* **Lab section sign-up: ~ 30 min. slot** **Lab 2 Pre-Lab Due**
Week 9 **Oct. 17 – Oct. 21**	***Friday, October 21*** *Lecture Lab 3: Introduction to Nanoindentation* (@218MEB) 11:00AM – 11:50AM **Lab 2 Report Due**

REGULAR LECTURE FRIDAY 8/26 @ 11am

Questions to discuss, think about for the course

- Why should we learn about mechanical properties of tissue
- What diseases affect mechanical properties?
- How are tissues different than “typical” engineering materials?
- What are some of examples of how tissues adapt?
- What are challenges associated with mechanical testing of biological tissue?
- What are composites? functional design
- Most biological materials have a hierarchical structure. What do we mean by hierarchical structure?
- What is a mechanical property of a material? Or a material property?

How is tissue different than “traditional” engineering materials like metals, ceramics, polymers in ME330?

Biological tissues are

- Living
- adapt to their environment,
- actively respond to stimuli
- bathed in body fluids (except for skin, nails, hair, hooves)
- complex composite materials
- have structural hierarchy
- Others: answers endorsed on ME 482 Piazza page…

Why do we want to learn about the changes or about mechanical properties and mechanics of tissues?

- Design replacements
- or use animal tissues to replace human tissue (e.g. porcine heart valves) as examples
- develop therapies and drugs
- understand diseases
- develop better health care guidelines
- diagnose disease

Understanding physical interactions of cells and tissues with the surrounding environment (physical) helps to understand morphogenesis, growth, remodeling, development, disease.

What are some examples of how tissue adapts?

- Weight lifters
- Astronauts
- Tennis players (playing arm a lot bigger)
- Muscle atrophy
- Callus formation
- Evolution – land animals vs sea animals and symmetry

<u>Functional form results from force input to the system.</u>

- e.g. weightlessness (zero or microgravity): no gravity → no weight on limbs → no muscle needed to maintain posture → the system does not work against gravity therefore diminishes its capacity to do so.
- Bone loss at a rate of 1%/month
- Muscle atrophy quickly
- Fluid shift to head → thickening of skull, renal complications, etc

NAME:_____

Student Questionnaire

Please fill out this questionnaire (front and back) and give to me. I will use it to learn your names, by learning something about you, and to learn about your academic background.

1) Why are you taking this course? What are your academic or personal interests in the course?

2) List other engineering or biology courses (include name not just number) you are currently taking. It is ok if you are not taking any, or have not taken any. No problem.

3) List the mechanics and materials behavior courses have you taken at UIUC or elsewhere (where?).

4) What other topics/courses have you had that would help me to learn about your background? Examples are below, but include any you think would be useful for me to know.

Tissue engineering	*Biological sciences*
Biomaterials	*Biomechanics (cell, tissue, or full body)*

5) If you are a graduate student, tell me a little about your research project. Who is your advisor? If you are an undergraduate, are you involved in research? With whom? Have you had internships?

6) Tell me some things about yourself. e.g. Where you are from? What are your hobbies? What do you do in your spare time? What are your extracurricular activities? In a band? Play a sport? Like to cook?

Class Project (35%)

How do disease states or conditions alter the mechanical properties of cells or tissues?

The purpose of this project is to research diseases that affect cell or tissue structure, composition, and mechanical properties. Students may work in pairs, but no two projects can be the same. You must "claim" your disease. Last year (2013) some students used Piazza to find a partner.

The objectives are to identify a disease (**not osteoporosis or osteoarthritis**), do an extensive literature search, and write a report that includes:

(1) **Quantitative*** **data** from multiple sources showing the associated change(s) in mechanical properties of the affected cells or tissues;
(2) **Detailed descriptions** of the changes in cell or tissue *structure* and *composition* that are responsible for the changes in mechanical properties.
(3) **Clinical implications**;
(4) A **summary of the mechanisms** by which the change(s) occur(s);
(5) **Current treatments** and/or therapies and treatments/therapies under development.

**If quantitative data is not available, choose another topic.*

General Format for written report (general requirements for presentation are same)

- Abstract (~200-300 words)
- Introduction (start broad, get specific, probably >1 but <3 pages)
  - Layman's description of the disease that any non-technical family member would understand
  - Who it affects (men? women? children? Particular ethnic group?)
  - How it affects them (in layman's terms) i.e. clinical implications
  - Economic impact (e.g. bone grafts cost billions/year etc)
  - Brief summary of the specifics of what the project/review will address
- Main Text must include the following information (organized as you wish):
  - More in depth technical description of the disease including a summary of the mechanisms by which the measured changes occur
  - More technical description of how it affects the patient – i.e. clinical implications
  - Specific, **quantitative changes** in mechanical properties
  - Specific changes in composition, structure, microstructure, etc.
  - Current treatments for the disease or treatments underdevelopment/in trials (at minimum), treatments being researched (probably about same length as introduction, not likely < 1 pg).
- Short paragraph at the end about why you chose the disease (don't forget this!).

Students must submit electronic documents with bibliography (and the corresponding endnote library or similar if possible). You will present your project during final exam period. This is one of the best parts of the project as it is interesting to learn from other projects. No two groups (of two) or individuals can do the same disease. You may use tables, graphs, and figures from literature as long as you ***cite them appropriately. This is critical.***

Grade (35%) based on:

- Brief project proposal to ensure that you have chosen an appropriate topic (5%).
  - It should include evidence from multiple sources (≥2) that the disease you have chosen results in measurable (i.e. quantitative not qualitative) changes in mechanical properties.
  - You should get all 5% - it will be iterative. This means if it is not done well, I will return it and ask you to do it again with the possibility of getting full credit.
- Paper Reviews to help you get you started on the literature review. (I will provide additional guidance on this later.) (20%)
- Presentation during the final exam period (30%)
- Written Report (45%)

Papers originating from class project…

JOURNAL OF THE MECHANICAL BEHAVIOR OF BIOMEDICAL MATERIALS 4 (2011) 223–236

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journal homepage: www.elsevier.com/locate/jmbbm

Review article

The effect of keratoconus on the structural, mechanical, and optical properties of the cornea

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Papers originating from class project…

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System-Level Biomechanical Approach for the Evaluation of Term and Preterm Pregnancy Maintenance

Preterm birth is the primary contributor to perinatal morbidity and mortality, with those born prior to 32 weeks disproportionately contributing compared to those born at 32–37 weeks. Outcomes for babies born prematurely can be devastating. Parturition is recognized as a mechanical process that involves the two processes that are required to initiate labor: rhythmic myometrial contractions and cervical remodeling with subsequent dilation. Studies of parturition tend to separate these two processes rather than evaluate them as a unified system. The mechanical property characterization of the cervix has been primarily performed on isolated cervical tissue, with an implied understanding of the contribution from the uterine corpus. Few studies have evaluated the function of the uterine corpus in the absence of myometrial contractions or in relationship to retaining the fetus. Therefore, the cervical-uterine interaction has largely been neglected in the literature. We suggest that a system-level biomechanical approach is needed to understand pregnancy maintenance. To that end, this paper has two main goals. One goal is to highlight the gaps in current knowledge that need to be addressed in order to develop any comprehensive and clinically relevant models of the system. The second goal is to illustrate the utility of finite element models in understanding pregnancy maintenance of the cervical-uterine system. The paper targets an audience that includes the reproductive biologist/clinician and the engineer/physical scientist interested in biomechanics and the system level behavior of tissues. [DOI: 10.1115/1.4023486]

Journal of Biomechanical Engineering **Copyright © 2013 by ASME** **FEBRUARY 2013, Vol. 135 / 021009-1**

Papers originating from class project (2015)

- Both are *almost* ready to submit…one will be submitted this week, the other in the next month or so.
  - Cerebral palsy and the effects on muscle structure-function- and mechanical properties
    - Two students – one mechanical, one kinesiology - and the advisor of one of the students
  - Rotator cuff tear and the mechanical properties of surrounding and involved tissue
    - three students from the class collaborated plus their advisor

Start thinking about your project topics:
What diseases do you know about that affect the mechanical properties of cells or tissues?

- Osteoporosis *(OFF LIMITS for project topic…pick something less obvious and well-known)*
- Rickets
  - Softening of bones due to lack of vit D, Ca, or P
- Osteoarthritis
  - Degradation of joints due to disease, aging, or injury
- Brittle bone disease
  - Collagen in bone does not organize properly, bone becomes brittle
- Malaria
  - Parasitic disease in which RBC become stiff
- Arthrosclerosis
  - Hardening of the arteries
- Cancer