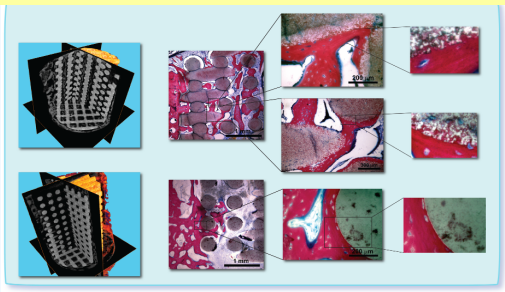
ME 482 Experimental Tissue Mechanics

Professor A. Wagoner Johnson

Wednesday, 8/24/16



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.

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Class Project Information

NOTE- I put the 2015 one in 8/22 lecture notes! This one and your handout are updated.

Wagoner Johnson ME 482: Experimental Tissue Mechanics 2016

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 are strongly encouraged to work in pairs**, but **no two projects can be the same**. You must "claim" your disease (sign-ups on Piazza). NEW! We will do some group activities to help facilitate interactions and encourage formation of project partnerships.

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.*

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General Format for written report (general requirements for presentation are same, more detail later in semester)

- 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***.

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Grade (35%, broken down as shown below).

The assignments are intended to help you to move your project forward throughout the semester rather than only at the end.

- Brief project proposal to ensure that you have chosen an appropriate topic (5%). Send to me by email.
  - It must include evidence from multiple sources (>3) that the disease you have chosen results in measurable (i.e. quantitative NOT qualitative) changes in mechanical properties.
  - You should get all 5%. If it is not done well or the topic and plan need some tweaking, I will return it and ask you to do it again with the possibility of getting full credit.
- Paper Reviews to help get started on the literature review. (I will provide additional guidance on this.) (20%)
- Project outline (more detail on assignment later) (10%)
- Presentation during the final exam period (25%)
- Written Report (40%)

Papers originating from class project…

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

ELSEVIER

available at www.sciencedirect.com

ScienceDirect

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

Publications 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

What is a composite? What are some examples of composites?

- Examples - Concrete, MMC, sandwich structures, chocolate chip cookies
- At least two or more constituents that together improve ≥1 properties over one of the constituents.
  - Heat transfer – engine applications
  - Strength to weight – aerospace
  - Weight – high performance bicycles
- *The amount, shape, and arrangement of the constituents dictates properties*
  - Matrix containing particles
  - Matrix containing fibers (draw, aligned, random, different lengths)
  - Sandwich structures
- Man-made composites are relatively simple and most do not adapt to environment. Although new "smart materials" are being developed.

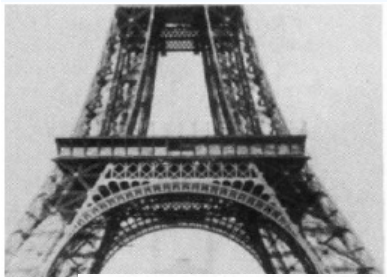
Tissues as composites

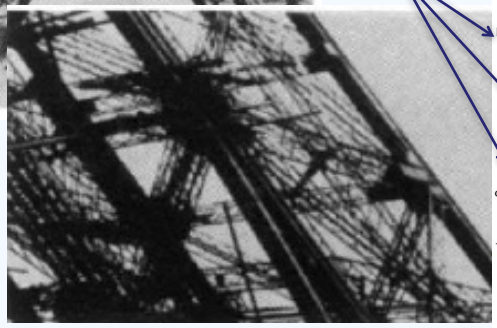
- Tissues are composites of cells, extracellular matrix, or ECM. ECM is a catch all encompassing everything besides the cells and means different things for different tissues. Usually consists of varying amounts of protein (like collagen or elastin) and ground substance (proteoglycans, water, other stuff).
- If we want to understand the behavior of a metal or composite – what do we do? We look inside at the structure, we look at the composition, because we might have other information that would help us to understand the behavior.
- To understand the mechanical behavior of tissues (here we consider cartilage, bone, tendon, and ligament) we need to understand the composition, structure, and arrangement of the constituents in just the same way.

Many biological materials have a hierarchical structure.

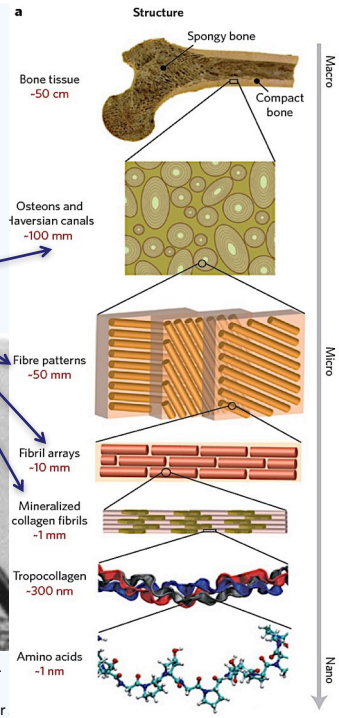
- What do we mean by hierarchical structure? (slide)
- Materials with structural hierarchy have structures within structures. Eiffel Tower, laminates, and tissues like bone, ligament, and tendon.
- Having structural hierarchy allows one to significantly improve properties (usually specific properties like property/density) as compared to the material alone.

Structural hierarchy





Should be microns, not mm



Lakes, 1993

Ritchie, Nat.Mat. 2011

for more info http://silver.neep.wisc.edu/~lakes/Hierarch.html)

Other examples of hierarchical structure – tadpole skin is a laminate with hierarchical structure

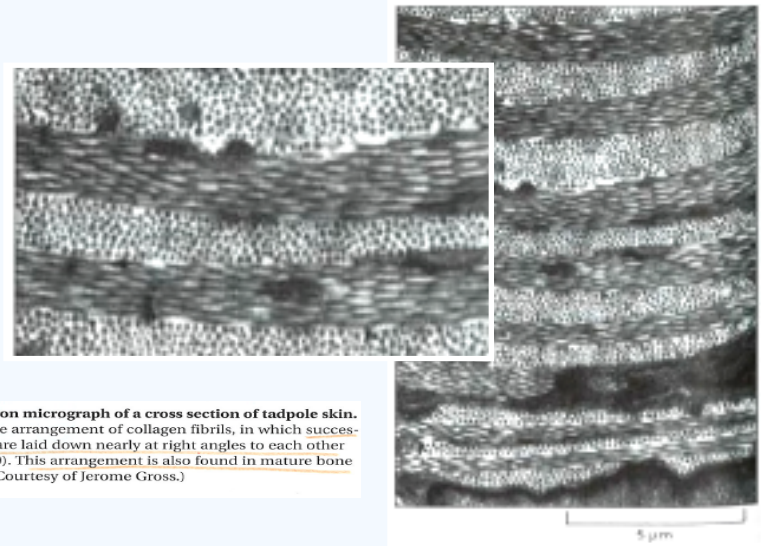


Figure 19–12 Electron micrograph of a cross section of tadpole skin. Note the plywoodlike arrangement of collagen fibrils, in which successive layers of fibrils are laid down nearly at right angles to each other (see also Figure 19–9). This arrangement is also found in mature bone and in the cornea. (Courtesy of Jerome Gross.)

(Alberts)

Hierarchy of Tendon (connects muscle to bone)

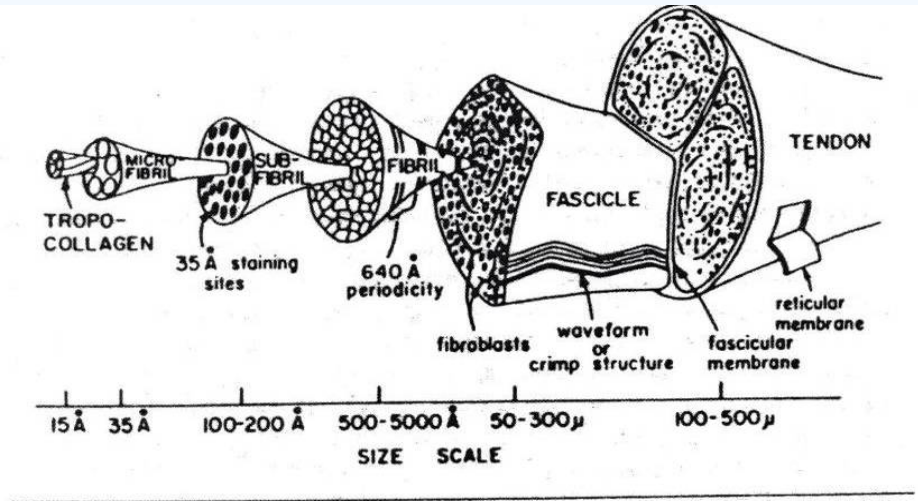


Figure 5.1 A schematic diagram of the structural hierarchy of tendon. Ligament and tendon are similar in structure; both are composed of smaller and smaller fiber bundles. The basic structural element is the tropocollagen molecule. (Reprinted by permission from Kastelic, Galeski, & Baer, 1978.)

Why does it matter to us in studying the tissues whether or not there is a structural hierarchy?

- How do we define a mechanical property of bone, for example? Whole bone? Part of the bone? If so what part? Osteons? Individual lamina?
- At what level do we define 'property?' At what level are properties important?
- What are "apparent properties?"

What are some challenges associated with characterization of mechanical properties of tissue?

Many will become apparent throughout the course!

- Limited number of samples and difficult to obtain
- Structure and composition change during collection and preparation
- Inhomogeneous structure – what part do you test?
- Complex tissue – difficult to obtain fundamental physical parameters – what does modulus mean?
- Tissue often cannot be frozen or stored without altering structure and properties
- In vitro and in vivo measurements do not always correlate, sometimes impossible