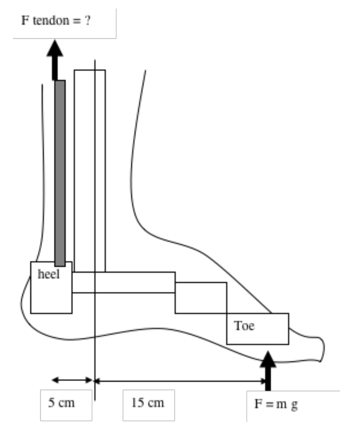
Biology 427 Biomechanics 2015

For this problem set assume that all biological materials are *Hookean* – that is their stress-strain relationship is linear.   The data in the list and table below are helpful in this assignment. Not all of the data need be used. Remember – it is always safer to show all your work.

Some Data (rounding to order of magnitude)
Human mass = 100 kg
Mass of a train car = 1000 kg
Human Achilles tendon length = 10 cm
Human Achilles tendon cross sectional area = 1 cm^2
Earth's gravitational acceleration = 10 m/s^2

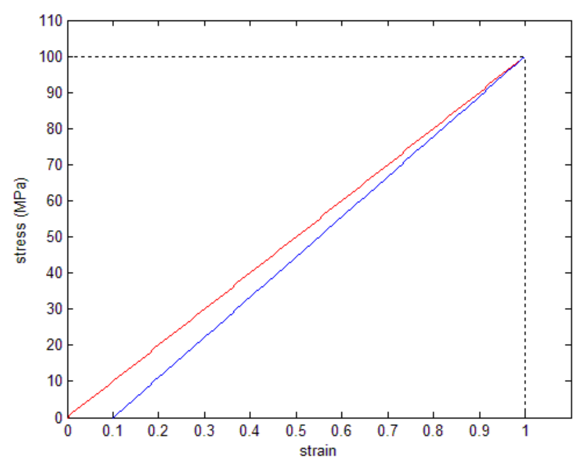
Material	**Stiffness (GN/m^2)**	**Strength (MPa)**	**Density (kg/m^3)**
Human bone	20.0	110	2000
Human tendon	0.6	82	1000
Human cartilage	0.02	1.4	1000
Clam shell	30	42	2700
Insect cuticle	9.5	95	1200
Crab cuticle	30	100	1900
Spider silk	5	350	1000

1. **Tendon stress and strain.** During slow walking, or in standing on the toes of one foot, your mass is supported by a small portion of the foot in contact with the ground. We are interested in computing the stress in the tendon of Achilles and the resultant strain (3 pts).



a) Compute the strain in the tendon from the stress you just calculated. Use this strain figure to compute the length change of the tendon.
b) Compute the strain energy per unit volume (area under a stress vs. strain plot) and the total strain energy (the area under a force vs. length plot) that this tendon absorbs.
c) During a vertical jump the force associated with your vertical acceleration adds increases the stress on your tendon. What is the maximum acceleration your tendon can withstand if you are jumping with one foot (as in the diagram)? (this is somewhat similar to a maximum landing deceleration you could tolerate without tendon rupture).

2. Stuff. You have come across a new material called "Stuff" and set out to test some of its material properties in a stuff tester, much like you did for intestinal tissue in lab. The graph below summarizes your measurements made while stretching the Stuff nearly to its breaking point (red line), then allowing the material to relax back to an unstrained state (blue line): Calculate the following material properties of Stuff:



a) Stiffness

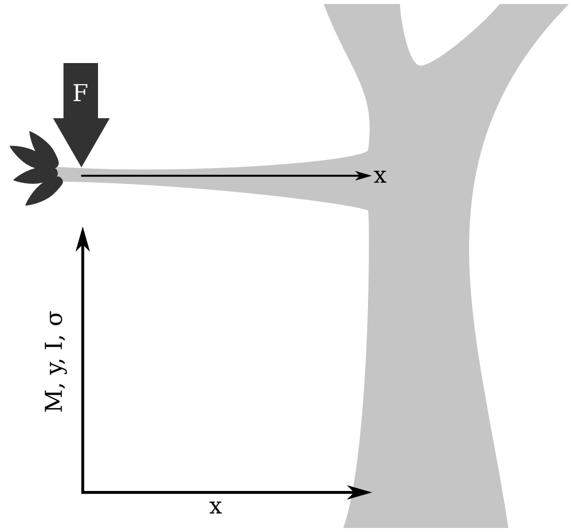
b) Maximum stress (strength) and strain (extensibility)

c) Work of Extension (energy input)

d) Resilience

3. The world wide web. In the Youtube clip of spider man (http://www.youtube.com/watch?v=GYOYewO_Veg) , the protagonist attempts to stop a speeding passenger train consisting of three cars traveling at 80 miles/hour. He shoots out 20 threads of spider silk (10 to the right and 10 to the left), each about 30 meters long. As you are aware, spider silk is among the strongest biomaterials known. Assume that all 20 threads have exactly the same diameter. What is the minimum thread diameter that is needed to stop the train? (Hint: what is the kinetic energy of the train?)

2. **Out on a limb.** In the tree diagrammed here, a force of 1000 N is exerted at the tip of the limb. The limb is 2 m long with a tip radius of 5 cm a base radius of 10 cm. The radius increases linearly from the tip to the base. Plot the stress along the stress along length of the beam. Where would you expect the limb to break (requires information from lecture on Oct 17)?



3. **Biomaterials Review Paper (3).** In the review by Meyers et al. (Science, 2013) the authors goal is to suggest a novel fabrication idea for the challenge of generating novel materials inspired by biology. The paper also reviews a large number of examples from natural systems ranging from toucan beaks to plant stems, with the idea that many of the forms they observe are reflecting purely mechanical design issues. In any one of the examples you read in this paper, can you suggest alternative hypotheses for the designs the authors discuss?