BME 315 Biomechanics Experiment 4

Deformation of tendon

Pre-lab assignment

Review lecture material on ligament structure and properties; also concepts of stress-strain curves and viscoelasticity. More details are provided in a tutorial document and a laboratory detail document available on the web. Several paper copies will be provided in the lab as well.

Plan test so that one person or person dissects the tendons from the tail; simultaneously others become familiar with the test frame by preliminary tests upon a rubber rod.

Dissection of rat tail tendon

Obtain a rat tail and check to make sure the rat tail is thawed. Be sure to wear gloves as this is biological tissue that is not prepped in cross linking agents such as formalin, which destroy possible disease causing agents but also change tissue properties. Rat tails will have the skin attached; skin must be removed before the tendons can be dissected out. Measure the tail length before dissecting.

Before making any incision, note the following: the tendons of interest are just below the skin but spaced evenly around the outer circumference of the tail. Therefore they can be easily damaged by even the most superficial cuts. To remove the skin, make an incision longitudinally from the superior aspect of the tail inferiorly towards, but not all the way to, the tip. Tendons appear white in color and can be easily avoided when making the longitudinal incision simply by analyzing the cross section of the tail where it was chopped off and determining tendon location. The skin may then be peeled off similarly to a sock, while using the scalpel to cut any connective tissue still attached. Multiple similar incisions may be necessary. After removing the skin dissect out one of the six or seven tendons by carefully cutting between the tendon and the tail bones. Start at the superior end of the tendon and continue inferiorly until the very tip of the tail. Tendons are continuous longitudinally for the entire length of the tail. Angle the cutting edge of the blade away from the tendon so it scrapes on the tail bones rather than damaging the tendon tissue.

Measure the diameter of the tendon at several points along its length using calipers provided in the laboratory. Measure the length of the tendon. Determine the tendon area using the following formula which is an ellipse approximation. Area = (Width x Height x Pi) / 4.

Do not pull, stretch or manipulate the tendon because small injuries to the fibrous structure will affect the experimental data. Do not let the tendon dry; this would change the mechanical properties of the tendon. Keep the tendon moist with water via a cotton swab or paper towel.

Testing

The small tensile test frames on the right in the first room entered in 1313 EH will be used.

Calibrate the frame following the detailed instructions provided.

Clamp the tendon into the pull test mounts. If the tendon slips out of the grips, you may use a cardboard or paper insert to distribute the gripping force. Do not let the tendon dry out.

Perform a *stretch to failure test* at constant deformation rate. Capture load versus time. Test several at a very different rate. As described in more detail below, calculate and *plot* stress versus strain, with the results for different rates compared on the same plot. Compare your results with results from the literature. Some results for ligament are provided in the class web resource.

Relaxation test. Stretch the tendon to about 1% or 2% strain, then hold it at constant extension. Use the fastest stretch speed to go from zero to prescribed strain. The reason is that relaxation is strictly defined as the load response to step function stretch. Calculate the time first. You will have to hit "stop" quickly. Monitor the force vs. time for 10 minutes. Let it recover 10 minutes, then repeat at 5% strain. Do not let the tendon dry out. Plot on the same graph stress vs. log time or log stress vs. log time for both strain values.

Analysis

For this lab, you will again have an extensive amount of data to manipulate. It is recommended that you use the program Matlab, which is found on the CAE lab computers, to work with this data. The data are in the form of a *.txt file, which can be uploaded into Matlab after commenting out (with a % symbol) the lines which do not contain numerical data.

1. Inspect your data for noise. If there is excessive noise, a filter is should be used to eliminate this noise. You can use a Butterworth filter in Matlab as presented in experimental details pages. Smoothing can also be done in KaleidaGraph.
2. Convert the voltage and time data from the tension tests into force and displacement. Plot force versus displacement for all the tension specimen data sets. As the time data started recording before the actual test was started, there will be data that needs to be eliminated before this plot is made. Inspect the calculated force data. When it begins to change, the test has been started. Use this information to determine how much data to remove and do so before making your plots. More detail is presented in experimental details pages.
3. Calculate and plot stress versus strain for all the tensile test data. The zero for force is clear and unambiguous. If the material were linear it would be straightforward to determine the zero for strain: the strain at which the stress begins to rise. Tendon and ligament are nonlinear: the stress increases gradually with strain at first. To identify the zero for strain, choose the strain at which the stress rises a factor of two above the noise. To see the noise, magnify the vertical scale.
4. Select one of the stress versus strain curves which you feel demonstrates the stress vs. strain response that you would anticipate. Label the toe region, linear region, yield strength, and ultimate strength points on this curve.
5. Calculate effective Young's modulus from the linear region of the curve for each of the tensile test specimens. Make a table with the following information for all of the tension test specimen: strain rate, Young's modulus, yield strength, yield strain, ultimate strength, ultimate strain.
6. Plot Young's modulus and yield strength versus the strain rate.
7. Plot the relaxation modulus (time dependent stress divided by the constant strain) versus time for the relaxation test specimen. Use a logarithmic scale for time. The stress scale may be linear or logarithmic. Overlay the results obtained at the two strains selected for study. The time from zero to full deformation is called the rise time. Do not show the rise time portion of the test because that is not relaxation. For the zero of the time scale, use the time halfway through the rise time. The zero time of course does not appear on a logarithmic scale. Plot the first data point for a time a multiple of three of the rise time.

Questions

1. Discuss what each of the labeled regions of the stress-strain curve (toe region, linear region, yield strength, and ultimate strength) represents or shows from a tendon property/physiology standpoint.
2. Consider the plot showing Young's modulus and the yield strength versus the strain rate. How do these parameters change with increasing strain rate? Does our tendon testing show the viscoelastic behavior that you would expect?
3. Consider the yield strength and yield strain of the tendon at different strain rates. If a tendon in your body experiences a very rapid loading (i.e. trying to catch yourself when you fall), how does the viscoelastic behavior increase or decrease your chance of experiencing an injury?
4. Consider the relaxation test specimen. Is the stress relaxation behavior best fit by the Maxwell, Voight, or Kelvin standard linear solid model or by a power law in time?
5. The time dependent viscoelastic response of a biological tissue is partly due to water being pushed out of the tissue. If the tendon dries out before testing, how might this affect the viscoelastic response?
6. What are the main sources of error in our measurements? How might this affect the calculations we have made? You may consider this question separately or within each of the previous questions, however make sure to discuss possible sources of error at some time.