BE 172 Spring 2018

Week X: Arterial mechanics. Experimental design.

Turn in this lab report at the final on June 11.
Also please upload an electronic version of the 2 page report via TritonEd

Objective

This lab will enable you to apply the exciting techniques you have learned throughout the quarter to design your own experiments to test the mechanical properties of arteries. You will need to plan your experiments before the lab day, then implement your experimental design in your lab session. Your goal is to use experimental results to determine elastic material properties of a blood vessel.

Background

Blood vessels are viscoelastic materials with nonlinear, anisotropic stress-strain relations. The vessel wall is a composite material composed of various layers made of different cell types and different proteins, thus non-homogeneous. The tissue itself is not static, but undergoes growth, resorption and remodeling in response to various mechanical and chemical stimuli. Thus it is evident that mathematical modeling of a blood vessel will involve several simplifying assumptions (especially for BE172!).

Blood vessels originate at the aorta and progressively branch to smaller and smaller vessels until the capillary network is formed in tissue, where the diameter of the capillary is typically about 8 microns. Arteries, arterioles, capillaries venules, and veins all have different structural properties, thus have functional mechanical differences. In this lab we will be investigating the mechanical properties of the large, elastic arteries.

The aorta and arteries in general are compliant thick-walled tubes. The elastin and smooth muscle in the vessel wall allow the diameter to distend during systole (high-pressure) and recoil during diastole. The arteries can also distend along their axis, and can twist and bend for example in extremities with large ranges of motion. Collagen in an artery provides tensile strength. The walls of an arterial blood vessel are themselves supplied with blood flow, which compounds a realistic analysis of wall mechanics.

Arterial mechanics have been investigated in great detail [1]. It is one of the most easily modeled tissues since the geometry is relatively simple and its function is not too complicated: the main purpose is to transport blood from one place to another. Properties of blood vessels which have been studied include constitutive equations [2], residual stress [3], stress [4][5], and studies examining the relationship between inflation pressure and vessel deformation [6].

In this lab we will examine mechanics of arteries by performing tests on isolated samples, and thus with appropriate assumptions, be able to determine direction-dependent properties of the material.

Equipment

• Previously used equipment can be used in the lab. Make a list of the equipment your station will require and submit it as part of your prelab. Include software for data acquisition. The most useful equipment will be the video camera, the force and displacement transducers, pulley wheel, micrometer and digital calipers. Note that the pressure gauges are NOT available.

• Other supplies will be available such as tubing and connectors, suture, surgical instruments, etc., and should be noted in your write up.

Tissue

• Artery samples, 1 per group, cylindrical, about 3-5 mm in diameter and 6-8 mm long.

Prelab Questions

There are no specific prelab questions, instead you must prepare an outline of the experiments that you will perform on the artery. Include sketches of your experimental set-up for each test, and equipment list, and experimental protocol for the 3 experiments you will perform, which describe the steps you will take to obtain the necessary information for each test. Also include a short description of what steps you will take to predict the mechanical properties of the vessel, for example, any modeling or structural assumptions. The prelab for this lab is obviously very important and will count for 30% of the lab report score. You should work on the prelab independently, then when the lab starts, compare notes with your lab partners and decide on the 3 tests the group will perform.

Artery tissue

You will be provided with samples of canine arteries in order to perform your experiments. The samples were obtained recently and were frozen until the day of the lab. Many external factors can affect the mechanics of a tissue specimen such as temperature, chemicals in the bathing solution, time, etc. You should mention these possible sources of variation in your write up, but you are not expected to control for them. Make sure to keep the sample moist with saline during your entire experiment.

Experimental Procedure

Stress is related to strain by an "elastic modulus" or "material parameter" tensor. In general the elastic parameter tensor has many components, especially for a realistic biological material. Each stress component is a function of several strain components and several elastic constants. In this lab, we will simplify the mathematical relation between stress and strain, and assume that each of the 6 independent stress components has some empirical relationship to the corresponding strain component, i.e. $\sigma_{ij} = f(e_{ij})$, with i,j = 1, 2 or 3 for the 6 independent components. We know these relationships are non-linear; the mathematical equation for this non-linear relation can be quite complicated, but experimental measurement of the relationship is possible. Thus there are essentially six possible “tests” that can be done on the vessel, each will allow you to determine one of the 6 material parameter relationships.

You must perform at least 3 different mechanical tests on your specimen. Each of these tests should lead to a determination of one of the 6 elastic material property relations of the vessel. Other properties, such as viscoelasticity, pressure-volume compliance, residual stress, etc. do not count as one of the 3 tests since they do not lead to direct determination of an elastic parameter. Remember that an inflation test with a pressure measurement cannot be used in this lab. A valid test, for example, would be to perform a uni-axial stress-strain test along the axial length (z axis) of the sample, finding $\sigma_{zz}= f(e_{zz})$. This would allow you to determine the “axial material parameter relation” which could be thought of as the tensile axial stiffness coefficient function, essentially the slope of the axial stress-strain curve. A properly applied torsional test on a cylinder gives values for one of the shear moduli (there would be 3 possible ‘shear’ tests). In a rotational test, you would need to find the shear stress (as a function of torque applied) and the shear strain (a function of the angle of rotation). You can use linear theory to determine these relations (i.e. shear strain is 1/2 tan(change in angle), reference [7]; shear stress is a little more complicated, but for the purposes here can be taken as torque/area analogous to force/area for normal stress). For each of the 3 types of tests, you should repeat the same test 3 times, to examine for experimental repeatability. Present the data from your experimental tests in your write-up as plots of stress vs. strain, and also as plots for the elastic modulus (slope of this curve). Thus you should have

6 graphs total in your report. You can average the 3 repeated tests, or present all 3 curves for each of the 3 tests used for each material parameter.

Data Analysis/Report

Your results should consist of the 6 plots described above (3 stress-strain and 3 modulus-strain). In all cases use stress vs. strain for the plots, not force or angle change. Describe how you obtained the stress-strain data form the actual acquired information. Your final "result" would be the 3 modulus plots for the 3 stress/strain components you have chosen. Label each plot with the proper component, for example "circumferential-axial elastic modulus relation". Remember for all of these tests, the vessel properties are non-linear, thus the result for the "modulus" will not be just one number, but a full curve.

Include brief explanations of the methods you used to obtain the data for each type of test, and limitations of the experiment and assumptions made for these analyses, and explanations of the results. You should also comment on the validity of finding these 6 possible moduli (see introduction above), since in reality they are not true elastic parameters of an anisotropic, non-linear, viscoelastic, three-dimensional material.

References

1. Fung, Y. C., 1981. Biomechanics: Mechanical Properties of Living Tissues. New York, Springer-Verlag Inc.
2. Chuong, C. J. and Fung, Y. C., 1984, "Compressibility and constitutive equation of arterial wall in radial compression experiments," J Biomech, Vol. 17, pp. 35-40.
3. Chuong, C. J. and Fung, Y. C., 1986, "On residual stress in arteries," J Biomech Eng, Vol. 108, pp. 189-192.
4. Doyle, J. M. and Dobrin, P. B., 1973, "Stress gradients in the walls of large arteries," J Biomech, Vol. 16, pp. 631-9.
5. Mirsky, I., 1973, "Ventricular and arterial wall stresses based on large deformation analyses," Biophys J, Vol. 13, pp. 1141-1157.
6. Patel, D. J., Greenfield, J. C. and Fry, D. L. (1964). In-vivo pressure-length radius relationships of certain blood vessels in man and dog. Pulsatile Blood Flow. E. O. Attinger. New York, McGraw-Hill**:** 293-305.
7. Fung, Y. C., 1994. Continuum Mechanics. Englewood Cliffs, Prentice Hall.