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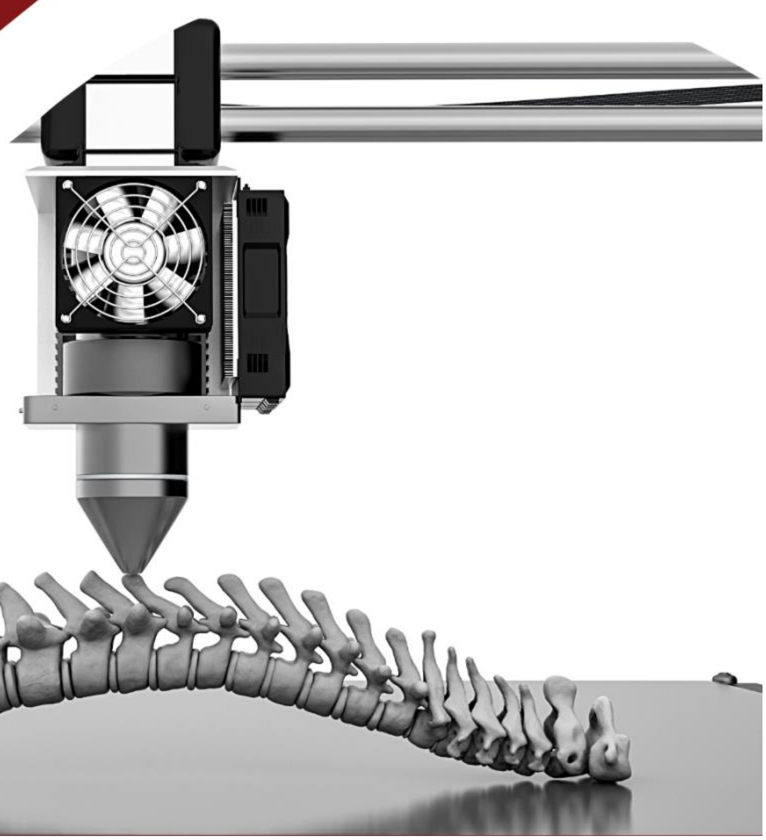
OPEN EDUCATIONAL RESOURCE

Biomedical Engineering Lab Manual

VOL. 1

Featuring Dry Lab Procedures

- Biomechanics
- Bioimaging
- Bioelectricity



This lab manual has been adapted from educational materials which have been prepared and refined by instructional staff of the University of Oklahoma School of Biomedical Engineering (SBME). Notably, Dr Rachel Childers is credited with the initial development of the original SBME lab courses and procedures. SBME project engineer Kirsten Jeffries and many SBME graduate and undergraduate teaching assistants have also played an important role in refining these past lab procedures and the current manual.

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Module 1 Introduction to Functional Human Models

<u>Pre Lab-Review</u>

Pre-Lab Checklist:

- ☐ Complete Lab Safety Training (Upload Certificate to Canvas)
- ☐ Complete CATME Team-Maker Survey
- ☐ Submit Pre-Lab 1 (Complete Quiz on Canvas)

Pre-Lab 1: Lever Systems in the Human Body

This pre-lab will be available on Canvas as a quiz with unlimited attempts and no time limit. Please use the space below to review and work on your questions before opening the quiz.

Question 1:

Label the mechanical elements for the lever system of the elbow in **Error! Reference source not found.**:

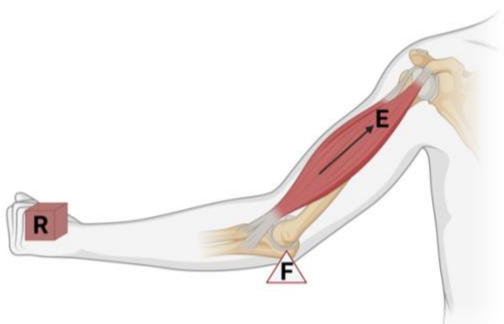


Figure 1-1 Anatomical image of the humeroulnar joint in a flexed position. *Created with BioRender.com*

E	_________________ force
F	
R	_________________ force

Question 2:

Label the anatomical names of the bones and muscles shown in Figure 1-2:

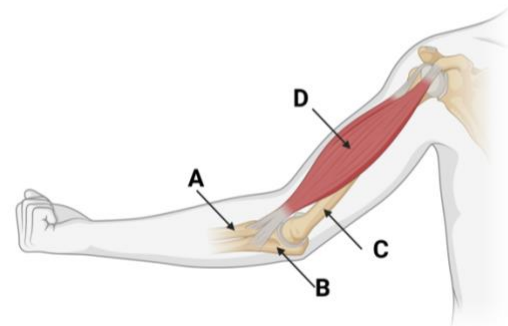


Figure 1-2 Anatomical image of the humeroulnar joint in a flexed position. *Created with BioRender.com*

A	
B	
C	
D	

Question 5:

List all joint movements, in each plane of motion, at the humeroulnar joint:

Plane of Motion	**Humeroulnar Joint Movements**
Sagittal	
Frontal	
Transverse	

Question 4:

Label the anatomical names of the bones and muscles shown in Figure 1-3:

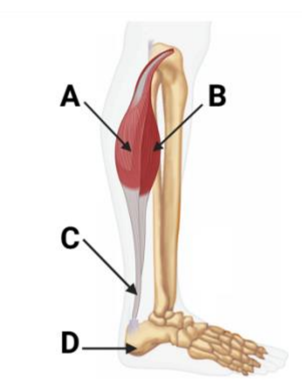


Figure 1-3 Anatomical image of the talocrural joint in a neutral position. *Created with BioRender.com*

A	
B	
C	
D	

Question 5:

List all joint movements, in each plane of motion, at the talocrural joint:

Plane of Motion	**Talocrural Joint Movements**
Sagittal	
Frontal	
Transverse	

Question 6:

FILL IN THE BLANKS: The concentric action (shortening to produce force) of muscle A in Figure 1-3 produces a [movement] joint movement at the [joint] joint?

movement	
joint	

Module 1 Lab Procedure

Introduction:

Humans produce and control movement, using the bones of the skeleton form a mechanical system with skeletal muscles, tendons, and ligaments to support the body against gravity. The principles of *lever systems* allow the *musculoskeletal system* to transmit *force* and produce *torque (moment of force)*. Developing a working knowledge of biomechanics is essential to fully understand human movement and function, which is central to the practices such as orthopedic medicine. In this laboratory you will use working upper and lower limb models, and your own body, to investigate how movement is accomplished by organized actions of the musculoskeletal system.

Learning Objectives

1. Identify & measure elements of a lever system

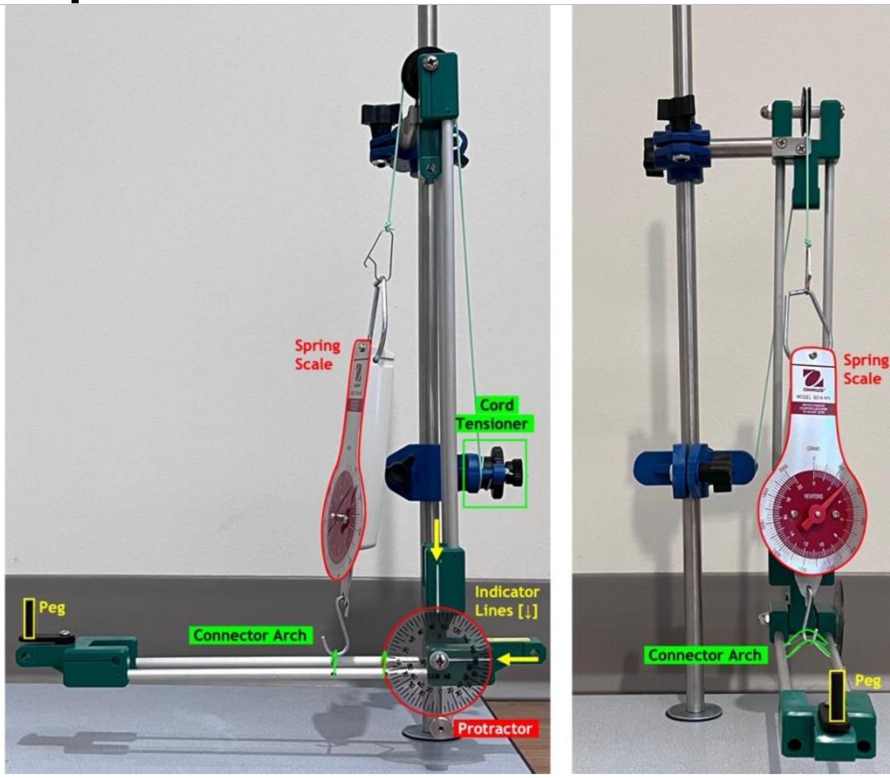
Materials

Upper Limb Model	Lower Limb Model
50 g mass	

Important Terms

Distal	
Proximal	
Humeroulnar joint	
Tibiofemoral joint	
Metatarsal phalangeal joint	
Angle	
Perpendicular	
Parallel	
Force	
Newtons	
Mass	
Weight	
Hysteresis	
Average	
Standard Deviation	

Setup:



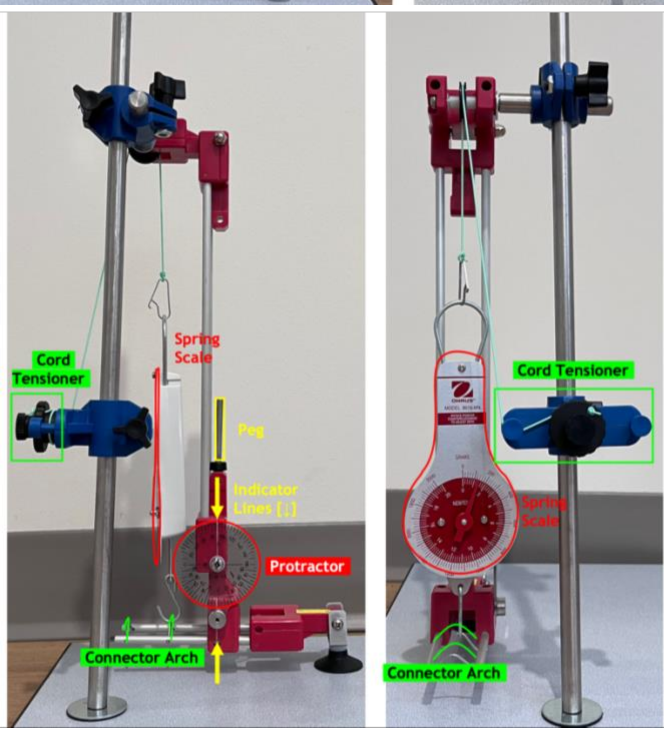
(a)

Upper Limb Model

Firstly, place the distal end of the forearm on the model base.

- Ensure upper arm is parallel to support pole
- Ensure upper arm is perpendicular to the base in the frontal plane
- For these adjustments use the model screws if needed

TERMS:
Peg, Mass, Spring Scale, Connector Arch, Cord Tensioner, Protractor, Indicator Line.



(b)

Lower Limb Model

Firstly, place the proximal end of the foot on the model base.

- Ensure leg is parallel to support post
- Ensure the leg is perpendicular to the base in the frontal planes
- Ensure the foot is in alignment with the leg
- For these adjustments use the model theme screws and the suction cup if needed.

TERMS:
Peg, Mass, Spring Scale, Connector Arch, Cord Tensioner, Protractor, Indicator Line.

Figure 1-4 Labelled images and setup tips for the upper (a) and lower limb (b) Vernier musculoskeletal models.

Procedure Part 1 (Arm Model)

Firstly, please make sure to setup the **arm** model as shown in Figure 1-4. Before proceeding, please check with your instructors that the model is setup correctly.

1.1. Lower the arm so the distal end is resting on the model base

1.2. Place a 50 g mass on the peg at the distal end of the arm, if required rotate the peg to a position most distal from the elbow joint.

1.3. Connect the spring scale to the most proximal connector arch.

1.4. Confirm that the spring scale reads 0 g before you proceed, ask your instructors for help if it does not read 0 g of force.

1.5. Using the cord tensioner, raise the forearm from its resting position to form a 90° angle with the upper arm.

a. MOVING THE ARM: The cord tensioner works best if you use two hands
   - i. Hold the larger barrel knob in position with one hand while you loosen (counterclockwise) the smaller locking knob with the other hand.
   - ii. Twist the barrel knob clockwise to raise the forearm to form a 90° angle with the upper arm.
   - iii. Tighten the smaller locking knob to secure the forearm in position

b. MEASURING ANGLES: The forearm angle is determined by the model protractor located at the elbow.
   - i. A 90° angle (perpendicular alignment) between the forearm and upper arm is formed when the 180°mark is aligned with the white indicator line on the lower pivot block at the elbow.
   - ii. It is helpful is you work as a team with one student operating the cord tensioner and changing forearm position and another viewing the protractor angle.
   - iii. Note: When using the protractor make sure it doesn't get stuck and is always freely movable.

1.6. Record data from the spring scale for the force required to support the forearm mass and 50 g added mass in Table 1-1.

a. Note: When using the spring scale, we want to avoid hysteresis. We will do this by gently tugging on the spring scale before making readings.

1.7. Repeat the procedure (Steps 1.1-1.6) at least 3-5 times, where team members will change roles. Each member of your student team should take at least one force measurement.

Table 1-1 Replicate and summary (average and standard deviation) data for the Force (g and N) required to support the arm and a 50 g mass in a flexed position (90°) is recorded along with the operator details.

MEASUREMENT	OPERATOR NAME	FORCE (g)	FORCE (N)
1			
2			
3			
4			
5			
AVERAGE			
STANDARD DEVIATION			

Procedure Part 2A (Leg Model)

The leg model is a little more challenging to conceptualize and relate to the human leg, so let's start with activities to clarify the setup of the leg model and how it relates to the human leg. It will help if you use physical motion of the foot and ankle to model movements and apply them to the model.

2A.1. Review the leg model in the image below. Firstly, using the letters (a-e) provided label the following anatomical components of the leg:

a. Tibiofemoral Joint Center
b. Leg Bones (Tibia & Fibula)
c. Talocrural Joint Center
d. Metatarsal phalangeal Joint
e. Posterior leg muscles (Gastrocnemius & Soleus)

2A.2. Now draw an illustration of the human leg in Figure 1-5 which matches the configuration and orientation of the leg model.

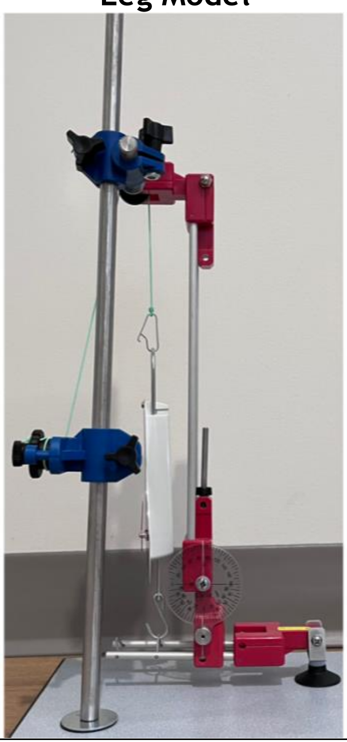
Leg Model	**Human Leg**
	

Figure 1-5 Musculoskeletal model of the leg and a matched drawing of the human leg

2A.3. With these model diagrams completed, which anatomical movement of the ankle and foot will be demonstrated by the leg model.

a. Ankle Motion (Talocrural Joint): ________________________________
b. Foot Motion (Metatarsal phalangeal Joint): ________________________________

2A.4. If you had a research participant in the lab and wanted to ask them to perform this movement what would you ask them to do (use nonscientific language to provide clear directions): ____

Procedure Part 2B (Leg Model)

Please make sure to setup the **leg** model as shown in Figure 1-4. Before proceeding, please check with your instructors that the model is setup correctly.

2B.1. Lower the leg so the proximal end is resting on the model base

2B.2. Connect the spring scale to the most proximal connector arch.

2B.3. Confirm that the spring scale reads 0 g before you proceed, ask your instructors for help if it does not read 0 g of force.

2B.4. Using the cord tensioner, raise the foot from its resting position to form a 90° angle with the leg.

PLEASE READ AND REVIEW POINTS 2B.4a + 2B.4.b THOROUGHLY BEFORE PROCEEDING

a. MOVING THE FOOT: The cord tensioner works best if you use two hands.
   i. Hold the larger barrel knob in position with one hand while you loosen (counterclockwise) the smaller locking knob with the other hand.
   ii. Twist the barrel knob clockwise to raise the foot to form a 90° angle with the leg, and parallel with the base. You may also need to reposition the suction cup in this step.
   iii. Tighten the smaller locking knob to secure the foot in position.

b. MEASURING ANGLES: The foot angle is determined by the model protractor located at the talocrural joint.
   i. A 90° angle (perpendicular alignment) between the foot and leg is formed when the 0°mark is aligned with the white indicator lines on both the top and bottom ankle blocks.
   ii. It is helpful is you work as a team with one student operating the cord tensioner and changing foot position and another viewing the protractor angle.
   iii. Note: When using the protractor make sure it doesn't get stuck and is always freely movable.

2B.5. Record data from the spring scale for the force required to support the foot in a parallel position in Table 1-2.

a. Note: When using the spring scale, we want to avoid hysteresis. We will do this by gently tugging on the spring scale before making readings.

2B.6. Repeat the procedure (Steps 2B.1-2B.5) at least 3-5 times, where team members will change roles. Each member of your student team should take at least one force measurement.

Table 1-2. Replicate and summary (average and standard deviation) data for the Force (g and N) required to support the foot in a parallel position is recorded along with the operator details.

MEASUREMENT	OPERATOR NAME	FORCE (g)	FORCE (N)
1			
2			
3			
4			
5			
AVERAGE			
STANDARD DEVIATION			

Post Lab Questions

We will conclude lab with a guided group discussion on the data your group, and section collected. Please take notes on this discussion below within the relevant question areas.

Data Validity

What is validity?

Is the data your group collected valid? Please provide reasoning to support your answer

Is your data valid?	
Reasoning	

Data Reliability

What is reliability?

Is the data your group collected reliable? Please provide reasoning to support your answer

Is your data valid?	
Reasoning	

Post Lab Activity

Post-Lab Checklist:

- ☐ Submit completed procedure and post lab questions (Upload completed pages 1:1-1:6)
- ☐ Complete Introduction Writing Assignment (Upload completed assignment pages 1:7-1:9)

Introduction Writing Assignment:

This assignment will introduce you to the grading rubric for you BME3171 Lab Report Introduction Section. Below you will find 4 separate activities where you will be required to review the requirements of each element of a lab report introduction and grade a sample report. For each section, please type in the provided green box.

Lab Report Introduction Section:

Scientific paper introductions typically have 3-4 main sections: [1] General Background, [2] Specific Information [3] The novelty or importance of the current experiment [4] A clear statement of your research questions or hypothesis.

1. **General Background:** Summarizes the purpose of the study and provides 2-3 examples of related previous work (with proper citation IEEE Style).

Please review the rubric for the general background section below:

RUBRIC	Missing	Poor	Developing	Average	Adequate	Excellent
[1] General Background	Not provided	Briefly Mentioned	Vague, background not relevant or inaccurate statements on the topic	Gives a general summary of the purpose of the experiment. Doesn't link background information to experiment. May provide one reference.	Concise introduction, appropriate length. Clearly links background information to experiment. Provides one reference.	Concise with relevant information pertinent to planned experiment. Real world uses stated. Provides 2-3 references of relevant studies.

Please review the sample general background section below:

The purpose of this study is the replication of the mechanics of the elbow and ankle joint in a manner that demonstrates how forces and torques are applied in the human body. The study utilized simple mechanical models, that simulated the bicep and the gastrocnemius, with a spring scale in place of the actual muscle and removable weights to replicate the weight of an actual limb. Similar studies have been conducted such as: "Application Of Optimization Principles In Determining The Applied Moments In Human Leg Joints During Gait[1]", which explored inverse dynamics to determine the applied moments at the lower joints of humans and "Muscles across the elbow joint: A biomechanical analysis[2]", which examined each muscle in the human arm for it's moments, forces, and its maximum work output.

[1] E. Y.-S. Chao and K. Rim, "Application of optimization principles in determining the applied moments in human leg joints during gait," *Journal of Biomechanics*, vol. 6, no. 5, pp. 497-510, Sep. 1973.

[2] K. N. An, F. C. Hui, B. F. Morrey, R. L. Linscheid, and E. Y. Chao, "Muscles across the elbow joint: A biomechanical analysis," *Journal of Biomechanics*, vol. 14, no. 10, pp. 659-669, 1981.

Which rubric category would you assign this general background section and why (please type in the green box):

RUBRIC CATEGORY	**Missing**	**Poor**	**Developing**	**Average**	**Adequate**	**Excellent**
JUSTIFICATION:						

2. **Specific Information:** Describes the variables, relationships and assumptions related to the experiment.
3. **Experimental Novelty:** Describes why you are doing this experiment and how it relates to human health

Please review the rubric for the specific information and experimental novelty sections below:

RUBRIC	Missing	Poor	Developing	Average	Adequate	Excellent
[2] Specific Information	Not provided	Briefly Mentioned	May not define all terms from hypothesis or may not be put into context	Correctly stated in context, terms from hypothesis may be incorrectly defined; some variables not explained fully	Clear statement of mechanical parameters; assumptions and relationships of the independent/ dependent variables of your hypothesis, but not explained; may be missing typical values from literature	Quantitative description of mechanical properties correctly stated including description of dependent and independent variables for hypothesis, assumptions and relationships clearly stated and explained; connections made to experiments that were tested, providing typical values from literature
[3] The novelty or importance of the experiment	Not provided	Problem not stated clearly. Justification is entirely personal and largely incoherent.	Irrelevant problem is stated. Justification is offered but largely personal and rambling.	Problem stated broadly. Justification is offered but is not sufficiently grounded in theory or literature.	Problem stated with clarity and specificity. Comprehensive background is articulated. Justification is clear and cognizant of previous research in the field.	Problem stated with high degree of clarity and specificity. Comprehensive background is articulated with brevity. Justification is sharp, logical, and extremely well informed. Draws specific connection to what is already known and the importance of the study.

Please review the sample specific information section below:

The analysis of the forces and moments acting on limbs relates to the field of biomechanics. The mechanics of how a muscle moves a limb and the moments/force that the muscle has to overcome are classified as Rigid Body Biomechanics. This study utilized a mechanical model of an elbow and ankle which depicted where the muscles applied forces on the bones and demonstrated the relationship between the force exerted by muscles, the moments produced by the muscles, and the force of gravity against the muscle's limb.

Which rubric category would you assign this **specific information section** and why (please type in the green box):

RUBRIC CATEGORY	**Missing**	**Poor**	**Developing**	**Average**	**Adequate**	**Excellent**
JUSTIFICATION:						

Which rubric category would you assign this **experimental novelty section** and why (please type in the green box):

RUBRIC CATEGORY	**Missing**	**Poor**	**Developing**	**Average**	**Adequate**	**Excellent**
JUSTIFICATION:						

4. **Hypothesis:** Includes a clear hypothesis and relates the summary of the experiments that will be performed to testing the hypothesis, hypothesis is verifiable based on the experimental procedure.

Please review the rubric for the hypothesis section below:

RUBRIC	Missing	Poor	Developing	Average	Adequate	Excellent
[4] Research Questions or Hypothesis	Not provided	Briefly Mentioned or not logical	Too little/too much or unnecessary info, does not flow well into the rest of the report; not logical or not measurable hypothesis	States specific goals of experiment, may not connect back to background info provided in the introduction or explain why the experiments are performed	Clearly stated, with connections drawn to background info, with brief summary of what experiments will be done and why; measurable hypothesis related to experimental design.	Clearly stated with relationship to background info, clear hypothesis stated, brief summary of what experiments will be done and why, flows well with intro and prepares reader well for the rest of the paper; hypothesis is measurable, worthwhile, and directly tested by experimental design

Please review the sample specific information section below:

Because both the biomedical models of upper limb and the leg would be experimented on in a state of static equilibrium, it was hypothesized that the magnitudes of the resistance moments and the effort moments would be equal.

Which rubric category would you assign this **hypothesis section** and why (please type in the green box):

RUBRIC CATEGORY	Missing	Poor	Developing	Average	Adequate	Excellent
JUSTIFICATION:						

Introduction Writing Reflection:

Leave this section blank until after you review your grades and justifications with your peers and instructors.

You will have the chance to compare your assigned grades and justifications to those of your peers and instructors. Please use the space below to take notes on differences and important conclusions you come to base on these comparisons. These notes will be very useful as you will submit your first lab report introduction for Module 2.

Module 2 Functional Human Models

Pre Lab-Review

Pre-Lab Checklist:

☐ Submit Pre-Lab 2 (Complete Quiz on Canvas)

Pre-Lab 2: Functional Human Models

This pre-lab will be available on Canvas as a quiz with unlimited attempts and no time limit. Please use the space below to review and work on your questions before opening the quiz.

Question 1:

Describe two ways that the *moment* of force can be increased on a lever arm?

1	
2	

Question 2:

FILL IN THE BLANKS:

When a system is stationary or in *translational equilibrium* the net [______] acting on the object is [____] N.

When a system is stationary or in *rotational equilibrium* the net [_______] acting on the object is [____] N.m.

Question 3:

FILL IN THE BLANKS:

When a system is stationary or in *translational equilibrium* the net [______] acting on the object is [____] N.

When a system is stationary or in *rotational equilibrium* the net [_______] acting on the object is [____] N.m.

Question 3:

As shown in Figure 2-1, Candice, holds a mass of 8 kg in her hand. The mass is 35 cm from the fulcrum or humeroulnar joint. Candice produces force with her biceps brachii muscle with an isometric muscle action to produce an effort force (F_e) of 837 N.

If Candice's arm is in rotational equilibrium what is the magnitude of the effort moment arm (cm).

Please assume, the mass of the forearm and hand are 0 kg, gravity is = 9.81 m/s² the forearm is parallel to the ground, the elbow is flexed at 90°.

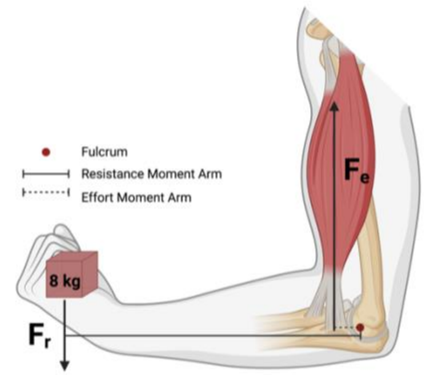


Figure 2-1 Anatomical image of the humeroulnar joint in a flexed position. *Created with BioRender.com*

Please upload a copy of this page to your canvas quiz to show your work.

Effort Moment Arm:	________ cm

Module 2 Lab Procedure

Introduction:

Humans produce and control movement, using the bones of the skeleton form a mechanical system with skeletal muscles, tendons, and ligaments to support the body against gravity. The principles of *lever systems* allow the *musculoskeletal system* to transmit *force* and produce *torque (moment of force)*. Developing a working knowledge of biomechanics is essential to fully understand human movement and function, which is central to the practices such as orthopedic medicine. In this laboratory you will use working upper and lower limb models, and your own body, to investigate how movement is accomplished by organized actions of the musculoskeletal system.

Learning Objectives

1. Identify & measure elements of a lever system
2. Appraise how gravity acts on a lever system
3. Define a moment & calculate its value in a lever system

Materials

Upper Limb Model	Lower Limb Model	Centimeter Ruler
	200 g	Calipers

Important Terms

Moment	
Fulcrum	
Vector	
Free Body Diagram	
Effort Force (F_e)	
Effort Moment Arm	
Resistance Force (F_r)	
Resistance Moment Arm	
Center of Gravity	
Biceps Brachii	
Gastrocnemius	
Percentage Difference	
Percentage Error	
Reliability	
Validity	

Assumptions

Procedure Part 1 (Arm Model)

Today we will measure effort and resistance forces, and moment arms, and calculate the effort moment and resistance moment for the arm model in a stationary position where the humeroulnar joint is flexed at 90°. We want to test the theory of rotational equilibrium. What is your Hypothesis for this experiment.

Theoretical Assumption being tested	
Dependent Variable(s):	
Control Variable(s):	
Hypothesis:	

Firstly, please make sure to setup the **arm** model as shown in Figure 1-4. Before proceeding, please check with your instructors that the model is setup correctly.

1.1. You will sketch a free-body diagram of the upper limb model in Figure 2-2. Use the picture as a reference, and the lines to the right to represent the free and fixed arms. Use the following steps to sketch and label the free-body diagram.

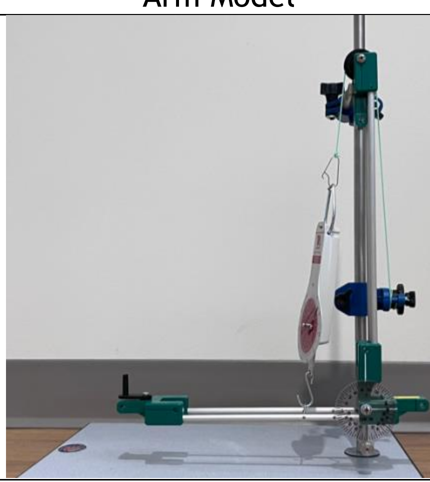
a. Draw a triangle pointing to the fulcrum, to show the point at which the arm is rotating.

b. Draw the *effort force* (F_e) of the Biceps Brachii. Locate its point of application on the free arm and draw an arrow, representing its vector, with its tail at the point of force application and its head in the direction the force is pulling.

c. Draw the effort moment arm, or *effort arm* (EA), using a bracket (|-----|) the length of the effort arm and label it EA.

d. Draw the resistance force (F_r) of the free arm. F_r should be represented as a vector with an arrow on the free-body diagram. To position the arrow correctly you need to locate the center of gravity (CoG) for the free arm. It is marked on one parallel rod of your model. Draw the resistance force arrow at the CoG in your free-body diagram.

e. Draw the resistance moment arm, or *resistance arm* (RA), using a bracket (|___|) the length of the effort arm and label it RA.

Arm Model	Arm Free Body Diagram
	

Required Elements Checklist	
	Fulcrum
	F_e
	EA
	CoG
	F_r
	RA

Figure 2-2 Mechanical arm model and arm free body diagram illustration.

1.2. Next you will collect data on the resistance and effort forces and moment arms:

a. Measure the F_e required to support the forearm, without a mass, at a position of 90° of elbow flexion. Record your results in Table 2-1(pay close attention to your units) under the effort row “Force (N)” column.

b. The mass of the free arm is indicated on a sticker near the pivot. Use this value to calculate F_r. Record your results in Table 2-1 (pay close attention to your units) under the resistance row “Force (N)” column.

c. Measure the length of the effort arm using a centimeter ruler or calipers. Enter the value in Table 2-1.

d. Measure the length of the resistance arm using a centimeter ruler or calipers. Enter the value in Table 2-1.

1.3. Using the data in Table 2-1, calculate the resistance moment (M_r) and the effort moment (M_e) and record them in the appropriate columns.

1.4. Using the data in Table 2-1 compare the two moments you calculated to determine the difference and percentage difference between them and record them in the appropriate row.

Table 2-1 Forces (N), Moment arm Lengths (cm) and resulting opposing moments (N-cm) are reported in the upper limb model. Difference and % difference are also reported between opposing moments.

	Force (N)	Moment Arm Length (cm)	Moment (N-cm)
Effort			
Resistance			
Difference			
% Difference			

Procedure Part 2 (Leg Model)

Today we will measure effort and resistance forces, and moment arms, and calculate the effort moment and resistance moment for the leg model in a stationary position where the foot is parallel to the base. We want to test the theory of rotational equilibrium. What is your Hypothesis for this experiment.

Theoretical Assumption being tested	
Dependent Variable(s):	
Control Variable(s):	
Hypothesis:	

Firstly, please make sure to setup the **leg** model as shown in Figure 1-4 Before proceeding, please check with your instructors that the model is setup correctly.

2.1. You will sketch a free-body diagram of the leg model below. Use the picture as a reference, and the lines to the right to represent the parallel rods, ankle, and foot. Use the following steps to sketch and label the free-body diagram.

a. Draw a triangle pointing to the fulcrum, to show the point at which the foot and leg is rotating.

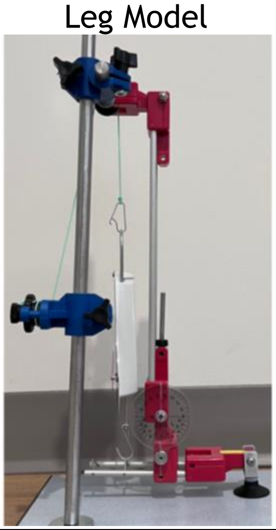
b. Draw the *effort force* (F_e) of the Gastrocnemius. Locate its point of application on the foot and draw an arrow, representing its vector, with its tail at the point of force application and its head in the direction the force is pulling.

c. Draw the effort moment arm, or *effort arm* (EA), using a bracket (|-----|) the length of the effort arm and label it EA.

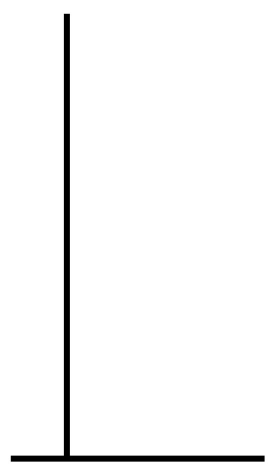
d. Draw the resistance force (F_r) of the total mass of the leg and foot. F_r should be represented as a vector with an arrow on the free-body diagram. To position the arrow correctly you need to locate the center of gravity (CoG) of the foot and leg. It is marked with a vertical white line on the lower ankle block. Draw the resistance force arrow at the CoG in your free-body diagram.

e. Draw the resistance moment arm, or *resistance arm* (RA), using a bracket (|____|) the length of the effort arm and label it RA.

Leg Model



Leg Free Body Diagram



	Required Elements Checklist
	Fulcrum
	F_e
	EA
	CoG
	F_r
	RA

Figure 2-3 Mechanical leg model and leg free body diagram illustration.

2.2. Next you will collect data on the resistance and effort forces and moment arms:

a. Measure the F_e required to raise the **foot parallel to the base**, with a 200 g mass on the pin above the ankle block. Record your results in Table 2-2 (pay close attention to your units) under the effort row “Force (N)” column.

b. The resistance force includes the force due to the mass placed on the model (200 g) and the mass of the foot and leg. The mass of the foot and leg is indicated on a sticker near the pivot. Use these mass values to calculate F_r. Record your results in Table 2-2 (pay close attention to your units) under the resistance row “Force (N)” column.

c. Measure the length of the effort arm using a centimeter ruler or calipers. Enter the value in Table 2-2.

d. Review your illustration in Figure 2-3 and measure the length of the resistance arm using a centimeter ruler or calipers. Enter the value in Table 2-2.

2.3. Using the data in Table 2-2, calculate the resistance moment (M_r) and the effort moment (M_e) and record them in the appropriate columns.

2.4. Using the data in Table 2-2, compare the two moments you calculated to determine the difference and percentage difference between them and record them in the appropriate rows.

Table 2-2 Forces (N), Moment arm Lengths(cm) and resulting opposing moments (N-cm) are reported in the lower limb model. Difference and % difference are also reported between opposing moments.

	Force (N)	Moment Arm Length (cm)	Moment (N-cm)
Effort			
Resistance			
Difference			
% Difference			

Post Lab Questions

We will conclude lab with a guided group discussion on the data your group, and section collected. Please take notes on this discussion below within the relevant question areas.

Hypothesis

When reviewing your group's data, does is support your group's hypothesis? Please provide reasoning to support your answer

Is your hypothesis supported?	
Reasoning	

When reviewing your section's data, does is support your group's hypothesis? Please provide reasoning to support your answer

Is your hypothesis supported?	
Reasoning	

Data Validity

Is the data your group collected valid? Please provide reasoning to support your answer

Is your data valid?	
Reasoning	

Data Reliability

Is the data your group collected reliable? Please provide reasoning to support your answer

Is your data valid?	
Reasoning	

Module 2 Post Lab Activity

Post-Lab Checklist:

- [ ] Document and submit completed procedure and post lab questions (Upload completed procedure page 2:1-2:6)
- [ ] Complete Introduction Writing Assignment (Group Assignment – details below)
- [ ] Complete Group Writing Assignment Submission Form

Group Introduction Writing Assignment:

This week you will work with your assigned group to prepare an introduction for the experiment you conducted for Module 2.

Is there a special format for our lab reports?

Yes, there is a lab report template which is required. Your submission will be returned and receive late penalty deductions if you fail to use the template. You can access the template for your introduction submission here or on your canvas page.

When citation relevant sources in your lab reports, you will need to use IEEE citation style. IEEE in-text citations consist of numbers provided in square brackets, which correspond to the appropriate sources in the reference list at the end of the paper. Please review the IEEE Reference Guide on their website.

How do I get an A grade?

To get an A grade your paper will need to meet most of the “Excellent” criteria in your rubric. There is an A standard introduction available for you to review on Canvas.

You previously used this rubric for your individual introduction writing assignment. Please review your post assignment reflection and the rubric provided below as you prepare your lab report introduction.

Can I get feedback on my group’s paper before submission?

Yes! Please come to office hours, your instructional team would be delighted to answer specific questions and once you have completed your paper review your rubric and paper self-assessment.

Introduction Rubric:

RUBRIC	Missing	Poor	Developing	Average	Adequate	Excellent
[1] General Background	Not provided	Briefly Mentioned	Vague, background not relevant or inaccurate statements on the topic	Gives a general summary of the purpose of the experiment. Doesn't link background information to experiment. May provide one reference.	Concise introduction, appropriate length. Clearly links background information to experiment. Provides one reference.	Concise with relevant information pertinent to planned experiment. Real world uses stated. Provides 2-3 references of relevant studies.
[2] Specific Information	Not provided	Briefly Mentioned	May not define all terms from hypothesis or may not be put into context	Correctly stated in context, terms from hypothesis may be incorrectly defined; some variables not explained fully	Clear statement of mechanical parameters; assumptions and relationships of the independent/ dependent variables of your hypothesis, but not explained; may be missing typical values from literature	Quantitative description of mechanical properties correctly stated including description of dependent and independent variables for hypothesis, assumptions and relationships clearly stated and explained; connections made to experiments that were tested, providing typical values from literature
[3] The novelty or importance of the experiment	Not provided	Problem not stated clearly. Justification is entirely personal and largely incoherent.	Irrelevant problem is stated. Justification is offered but largely personal and rambling.	Problem stated broadly. Justification is offered but is not sufficiently grounded in theory or literature.	Problem stated with clarity and specificity. Comprehensive background is articulated. Justification is clear and cognizant of previous research in the field.	Problem stated with high degree of clarity and specificity. Comprehensive background is articulated with brevity. Justification is sharp, logical, and extremely well informed. Draws specific connection to what is already known and the importance of the study.
[4] Research Questions or Hypothesis	Not provided	Briefly Mentioned or not logical	Too little/too much or unnecessary info, does not flow well into the rest of the report; not logical or not measurable hypothesis	States specific goals of experiment, may not connect back to background info provided in the introduction or explain why the experiments are performed	Clearly stated, with connections drawn to background info, with brief summary of what experiments will be done and why; measurable hypothesis related to experimental design.	Clearly stated with relationship to background info, clear hypothesis stated, brief summary of what experiments will be done and why, flows well with intro and prepares reader well for the rest of the paper; hypothesis is measurable, worthwhile, and directly tested by experimental design
Grammar, Spelling and Formatting	Clearly not proofread, inappropriate report length	Several errors, text in figures too small		A few errors, major sections labeled with headings, appropriate report length	Less than 2 errors, headings and sub-headings used	Correct grammar and spelling, legible text, headings, and sub-headings used
References	No references cited	No relevant references cited. references not cited in a consistent format; some references might be from Wikipedia		At least one relevant reference cited. Several missing citations supporting claims.	At least two relevant references cited.	Two or more *relevant* references cited appropriately. All statements requiring citation are cited using IEEE style.

Module 3 Musculoskeletal Lever Systems

Pre Lab-Review

Pre-Lab Checklist:

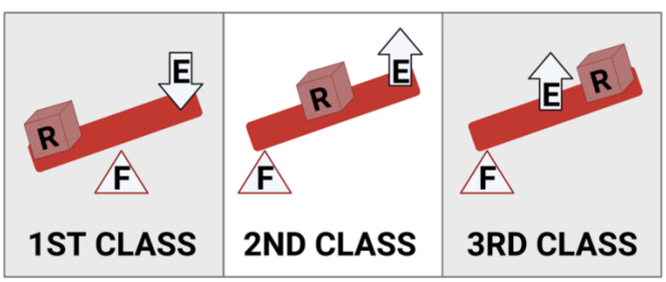
- [ ] Submit Pre-Lab 3 (Complete Quiz on Canvas)

Pre-Lab 3: Musculoskeletal Lever Systems

This pre-lab will be available on Canvas as a quiz with unlimited attempts and no time limit. Please use the space below to review and work on your questions before opening the quiz.

Introduction:

In Module 1 you reviewed the principles of lever system function using arm and leg models. In both models, the effort and resistance arms are located on the same side of the pivot, but the exact arrangement differs between the two. In Module 2, you will investigate the advantages and limitations of musculoskeletal levers systems with three different arrangements. The structure of each has special advantages and limitations.



In a ***1ST CLASS lever system***, the fulcrum (F) is centrally located between the opposing effort force (E) and resistance (R) forces. In the human body, rotating the skull on the atlas and axis in the action of looking up or nodding utilizes a first-class lever system.

In a ***2ND CLASS lever system***, the resistance (R) is centrally located between the effort (E) force and the fulcrum (F). Common examples of this are a wheelbarrow or bottle opener. In the body, the leg/foot are a second-class lever system.

In a ***3RD CLASS lever system***, the effort force is centrally located between, the resistance (R) and the fulcrum (F). A pair of tweezers is an everyday object example. The biceps acting on the forearm is an example from the human body.

Figure 3-1 A schematic of a first-, second- and third-class lever, along with a description of each lever type. Created with BioRender.com

Question 1:

What class lever system is formed by the humeroulnar joint when the triceps brachii straightens (extends) the elbow against gravity. Please explain your reasoning and *use IEEE style for any citations you choose to include. (Citations are not required).*

Lever class	
Reasoning	

Question 2:

Do some research using peer reviewed journal articles and investigate the lever system formed by the human mandible (jaw) when the jaw closes. What class lever system is formed by the mandible joint when the jaw closes. Please explain your reasoning and *use IEEE style for any citations you include (Citations are required)*.

Lever class	
Reasoning	
IEEE Full Citation for journal articles	[Ref number] Author's initials. Author's Surname, "Title of article," Title of journal abbreviated in Italics, vol. number, issue number, page numbers, Abbreviated Month Year, doi. e.g. M. M. Chiampi and L. L. Zilberti, "Induction of electric field in human bodies moving near MRI: An efficient BEM computational procedure," *IEEE Trans. Biomed. Eng.*, vol. 58, pp. 2787–2793, Oct. 2011, doi: 10.1109/TBME.2011.2158315.

Question 3:

Write two hypotheses related to 1) how much force it will take to support a 100 g mass on the upper limb model and 2) how much force it would take to support a 100 g mass on the leg model.

- assume the models are positioned as follows:
    - Forearm parallel to ground and the humeroulnar joint flexed at 90°.
    - Foot parallel to the ground and the talocrural joint in neutral position.
- you can ignore the force to support the models themselves
- the length of the upper limb model from "hand" to elbow" is 25.0 cm

You should be able to reference measurements in your module 1 and 2 notes.

Please provide numerical answers to the nearest whole number (g) [e.g., 25 g].

HYPOTHESIS 1 ARM:

FILL IN THE BLANKS: Since the upper limb model is a [____] class lever system and has a mechanical advantage [_______] * than 1, if a 100 g weight is placed on the leg model the force required to support the 100 g weight will be [_______] * than the load. The estimated force is [___] g based on the dimensions of the model.

** pick one of the following: **greater** / **less***

HYPOTHESIS 2 LEG:

FILL IN THE BLANKS: Since the lower limb model is a [____] class lever system and has a mechanical advantage [_______] * than 1, if a 100 g weight is placed on the leg model the force required to support the 100 g weight will be [_______] * than the load. The estimated force is [___] g based on the dimensions of the model.

** pick one of the following: greater / less*

Module 3 Lab Procedure

Introduction:

A lever is a nearly rigid object rotated about an axis. There are three types of levers systems, and different levers can magnify *speed* or *force* and produce *torque (moment of force)*. Most human body segment levers magnify speed because the effort moment arm is less than the resistance moment arm for the force being overcome.

Learning Objectives

1. Compare the structural organization of first-, second-, and third-class level systems in the human body.
2. Calculate the mechanical advantage of second- and third-class lever systems.
3. Compare the capacity of lever systems to act as force or speed/distance multipliers.

Materials

Upper Limb Model	Lower Limb Model	Centimeter Ruler
100 g mass		Calipers
		Sketch Paper & Pen

Important Terms

Displacement	
Height	
1st Class Lever	
2nd Class Lever	
3rd Class Lever	
Mechanical Advantage	
Ratio	
Reliability	
Validity	

Assumptions

Setup:

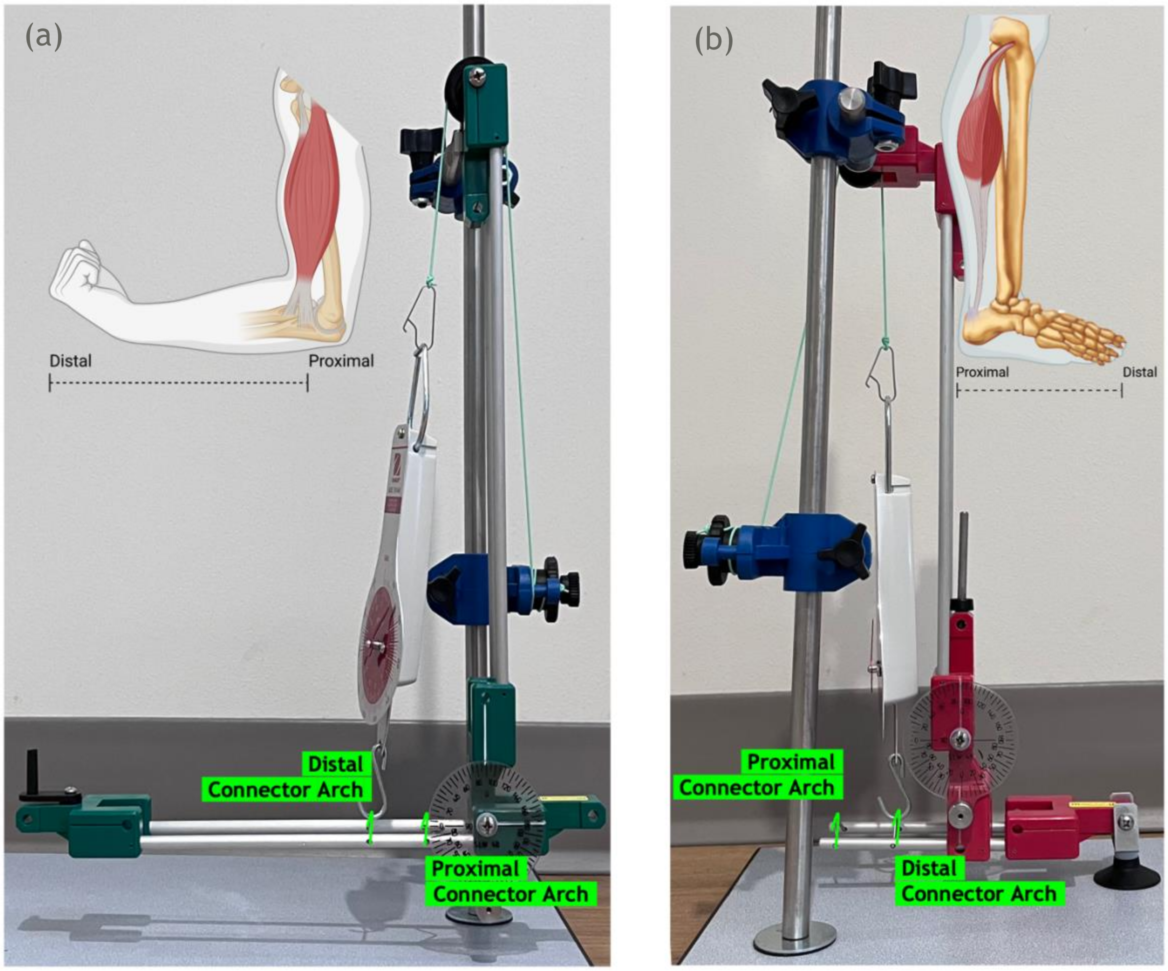


Figure 3-2 Labelled images illustrating the proximal and distal connector arches for the upper (a) and lower limb (b) Vernier musculoskeletal models. *Some image components were created with BioRender.com*

Special notes on model setup:

UPPER LIMB MODEL:

- The vertical position of the arm model will need to be setup so that the protractor is ~ 2.0 cm above the base.
- You will need to make marks on the base of the model, please tape the paper provided to the base of your arm model.

LOWER LIMB MODEL:

- You will need to make marks on the base of the model, please tape the paper provided to the base of your leg model.

Procedure Part 1 (Arm Model)

Today we will measure effort and resistance forces, and moment arms, for the arm model in a stationary position and the humeroulnar joint is flexed at 90°. The biceps brachii insertion point will be placed in two positions; one proximal position and one more distal position.
What is your Hypothesis for this experiment.

Independent Variable(s):	
Dependent Variable(s):	
Control Variable(s):	
Hypothesis:	

Firstly, please make sure to setup the **arm** model with the spring scale at the proximal connector arch. Before proceeding, please check with your instructors that the model is setup correctly.

Effort Force to hold 100 g

1.1. Firstly, lets collect data on force required to support a 100 g mass on the arm when the spring scale is connected at the proximal connector arch (Bicep Brachii (BB) proximal insertion (EA1)):

a. Measure the F_e required to support the forearm, without a mass, at a position of 90° of elbow flexion. Record your results in Table 3-1.

b. Measure the F_e required to support the forearm, plus a mass 100 g, at a position of 90° of elbow flexion. Record your results in Table 3-1.

c. Calculate the F_e required to support 100 g alone. Record your results in Table 3-1

1.5. Now move the spring scale to the distal connector arch (Bicep Brachii (BB) distal insertion (EA2)):

d. Repeat steps a to c and record your results in Table 3-1.

Table 3-1 Effort forces Fe (N) are reported for supporting the forearm, the forearm plus 100g, and 100 g mass. These are reported for the proximal and distal Biceps Brachii (BB) insertion points.

	F_e (N) Forearm	F_e (N) Forearm + 100 g	F_e (N) 100 g
BB Proximal Insertion (EA1)			
BB Distal Insertion (EA2)			

Mechanical Advantage

1.6. Move the spring scale to connect at the proximal connector arch (Bicep Brachii (BB) proximal insertion (EA1)):

a. Measure the length of the effort arm using a centimeter ruler or calipers. Enter the value in Table 3-2.

b. Measure the length of the resistance arm for the 100 g mass. Enter the value in Table 3-2.

c. Calculate the Mechanical advantage for this arm model configuration. Record your results in Table 3-2.

1.7. Move the spring scale to connect at the distal connector arch (Bicep Brachii (BB) distal insertion (EA2)):

a. Repeat steps a– c and record your results in Table 3-2.

Table 3-2 Moment arms (cm) are reported for the arm model effort and resistance moments. These are reported for the proximal and distal Biceps Brachii (BB) insertion points.

	Effort Arm (cm)	Resistance Arm (cm)	Mechanical Advantage
BB Insertion Proximal (EA1)			
BB Insertion Distal (EA2)			

Distance / Speed Advantage

If not already completed, please make sure to setup the vertical position of the **arm** model so the protractor is ~ 2.0 cm above the base. Before proceeding, please check with your instructors that the model is setup correctly.

BB DISTAL INSERTION

Ensure the spring scale is connected at the distal connector so the biceps brachii (BB) insertion point is at the most distal point

1.8. With the biceps brachii (BB) insertion point at the distal point, and the elbow "relaxed" with the forearm on the model base.

a. Use the ruler to measure the vertical position (cm) (from the base), of the BB insertion point.

i. On the sketch paper mark and label (BB_1) the base of the ruler to indicate the horizontal position of the BB insertion point.

b. Use the ruler measure the vertical position (cm) (from the base), of the 100 g mass.

ii. On the sketch paper mark and label (Mass_1) the base of the ruler to indicate the horizontal position of the 100 g mass.

Think about experimental reliability here, pick a specific non-movable location to characterize the BB insertion point and the 100 g mass.

1.9. Use the protractor and the indictor lines on the lower elbow block to move the forearm to a position of approximately 120° elbow flexion (See Figure 3-3).

a. Use the ruler to measure the vertical position (cm) of the BB insertion point (from the base), in this flexed position.

iii. On the sketch paper mark and label (BB_2) the base of the ruler to indicate the horizontal position of the BB insertion point.

b. Use the ruler measure the vertical position (cm) of the 100 g mass (from the base), of the 100 g mass, in this flexed position.

iv. On the sketch paper mark and label (Mass_2) the base of the ruler to indicate the horizontal position of the 100 g mass.

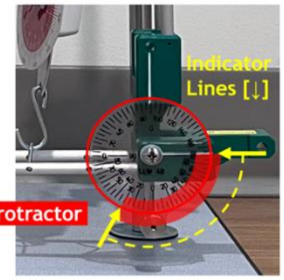


Figure 3-3 Labelled image showing 120 degrees of elbow flexion, guided with vernier model protractor and indicator lines.

1.10. Calculate the magnitude of the BB Insertion point resultant displacement between a resting and flexed position.

a. Calculate the magnitude of BB Insertion point vertical displacement by subtracting the value for BB Insertion point vertical position in a resting position (See step a) from the value in a flexed position (See step a) Record your data in Table 3-3.

b. Measure the magnitude of the horizontal displacement of the BB insertion point by measuring between mark BB_1 and BB_2. Record your data in Table 3-3.

c. Use Pythagoras theorem to calculate the magnitude of the resultant displacement of the BB Insertion point. Record your data in Table 3-4.

1.11. Calculate the magnitude of the 100 g mass resultant displacement between a resting and flexed position.

a. Calculate the magnitude of the 100 g mass vertical displacement (cm) by subtracting the value for 100 g mass vertical position in a resting position (See step b) from the value in a flexed position (See step b) Record your data in Table 3-3.

b. Measure the magnitude of the horizontal displacement (cm) of the 100 g mass by measuring between mark Mass_1 and Mass_2. Record your data in Table 3-3.

c. Use Pythagoras theorem to calculate the magnitude of the resultant displacement of the 100 g mass. Record your data in Table 3-4.

1.12. Calculate the ratio between the resultant displacements of the 100 g mass and the BB displacement. Record your results in Table 3-4.

1.13. Calculate the velocity of the BB and the 100 g mass resultant displacements. Assume movement time is 1 second. Record your results in Table 3-5.

BB PROXIMAL INSERTION

1.14. Move the spring scale to connect at the proximal connector so the biceps brachii (BB) insertion point is at the most proximal point.

1.15. Repeat steps 1.8 to 1.13 and add data to appropriate tables.

Table 3-3 Displacements of the resistance load moved by the arm model. Displacement magnitudes (cm) are reported for the Biceps Brachii (BB) insertion point and the 100 g mass, in the vertical, horizontal, and resultant directions. These are reported for the proximal and distal BB insertion points.

	BB Vertical Displacement (cm)	BB Horizontal Displacement (cm)	BB Resultant Displacement (cm)
BB Insertion Proximal (EA1)			
BB Insertion Distal (EA2)			
	100 g Vertical Displacement (cm)	**100 g Horizontal Displacement (cm)**	**100 g Resultant Displacement (cm)**
BB Insertion Proximal (EA1)			
BB Insertion Distal (EA2)			

Table 3-4 Resultant displacement magnitudes (cm) for the Biceps Brachii (BB) insertion point and the 100 g mass, and their ratios are reported for the proximal and distal BB insertion points.

	BB Resultant Displacement (cm)	100 g Resultant Displacement (cm)	Ratio of Displacement (mass:BB)
BB Proximal Insertion (EA1)			
BB Distal Insertion (EA2)			

Table 3-5 Velocity (cm/s) for the Biceps Brachii (BB) insertion point and the 100 g mass, are reported for the proximal and distal BB insertion points.

	BB Velocity(cm/s)	100 g mass Velocity (cm/s)
BB Proximal Insertion (EA1)		
BB Distal Insertion (EA2)		

Procedure Part 2 (Leg Model)

Today we will measure effort and resistance forces, and moment arms, for the leg model in a stationary position and the talocrural joint is in a neutral position The gastrocnemius insertion point will be placed in two positions; one proximal position and one more distal position. What is your Hypothesis for this experiment.

Independent Variable(s):	
Dependent Variable(s):	
Control Variable(s):	
Hypothesis:	

Firstly, please make sure to setup the **leg** model with the spring scale at the most proximal connector arch. Before proceeding, please check with your instructors that the model is setup correctly.

Effort Force to hold 100 g

1.16. Firstly, lets collect data on force required to support a 100 g mass on the leg when the spring scale is connected at the proximal connector arch (Gastrocnemius (GC) proximal insertion (EA1)

d. Measure the Fe required to support the leg, without a mass, at a position where the foot is parallel to the base. Record your results in Table 3-6.

e. Measure the Fe required to support the leg, plus a mass 100 g, at a position where the foot is parallel to the base. Record your results in Table 3-6.

f. Calculate the Fe required to support 100 g alone. Record your results in Table 3-6

1.17. Now move the spring scale to the distal connector arch (Gastrocnemius (GC) distal insertion (EA2)):

g. Repeat steps d to f and record your results in Table 3-6.

Table 3-6 Effort forces Fe (N) are reported for supporting the leg, the leg plus 100g, and 100 g mass. These are reported for the proximal and distal Gastrocnemius (GC) insertion points.

	F_e (N) Forearm	F_e (N) Forearm + 100 g	F_e (N) 100 g
GC Proximal Insertion (EA1)			
GC Distal Insertion (EA2)			

Mechanical Advantage

1.18. Move the spring scale to connect at the proximal connector arch (Gastrocnemius (GC) proximal insertion (EA1)):

h. Measure the length of the effort arm using a centimeter ruler or calipers. Enter the value in Table 3-7.

i. Measure the length of the resistance arm for the 100 g mass. Enter the value in Table 3-7.

j. Calculate the Mechanical advantage for this leg model configuration. Record your results in Table 3-7.

1.19. Move the spring scale to connect at the distal connector arch (Gastrocnemius (GC) distal insertion (EA2)):

k. Repeat steps h to j and record your results in Table 3-7.

Table 3-7 Moment arms (cm) are reported for the leg model effort and resistance moments. These are reported for the proximal and distal Gastrocnemius (GC) insertion points.

	Effort Arm (cm)	Resistance Arm (cm)	Mechanical Advantage
GC Insertion Proximal (EA1)			
GC Insertion Distal (EA2)			

Distance / Speed Advantage

GC DISTAL INSERTION

Ensure the spring scale is connected at the distal connector so the gastrocnemius (GC) insertion point is at the most distal point

1.20. With the Gastrocnemius (GC) insertion point at the most distal point and the foot "relaxed" with the foot parallel to the base.

l. Use the ruler to measure the vertical position (cm) (from the base), of the Gastrocnemius (GC) insertion point.

v. On the sketch paper mark and label (GC_1) the base of the ruler to indicate the horizontal position of the GC insertion point.

m. Use the ruler to measure the vertical position (cm) (from the base), of the 100 g mass.

vi. On the sketch paper mark and label (Mass_1) the base of the ruler to indicate the horizontal position of the 100 g mass.

Think about experimental reliability here, pick a specific non-movable location to characterize the BB insertion point and the 100 g mass.

1.21. Use the protractor and indictor lines on the lower ankle block to move the ankle joint into approximately 30° of plantar flexion.

n. Use the ruler to measure the vertical position (cm) of the Gastrocnemius (GC) insertion point (from the base), in this flexed position.

vii. On the sketch paper mark and label (GC_2) the base of the ruler to indicate the horizontal position of the GC insertion point.

o. Use the ruler to measure the vertical position (cm) of the 100 g mass (from the base), of the 100 g mass, in this plantar flexed position.

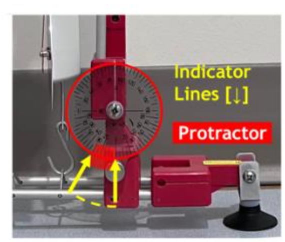


Figure 3-4 Labelled image showing 30 degrees of ankle plantarflexion, guided with vernier model protractor and indicator lines.

viii. On the sketch paper mark and label (Mass_2) the base of the ruler to indicate the horizontal position of the 100 g mass.

1.22. Calculate the magnitude of the GC Insertion point resultant displacement between a resting and flexed position.

p. Calculate the magnitude of GC Insertion point vertical displacement by subtracting the value for GC Insertion point vertical position in a resting position (See step l) from the value in a flexed position (See step n) Record your data in Table 3-8.

q. Measure the magnitude of the horizontal displacement of the BB insertion point by measuring between mark GC_1 and GC_2. Record your data in Table 3-8.

Use Pythagoras theorem to calculate the magnitude of the resultant displacement of the GC Insertion point. Record your data in

r. Table 3-9.

1.23. Calculate the magnitude of the 100 g mass resultant displacement between a resting and flexed position.

s. Calculate the magnitude of the 100 g mass vertical displacement (cm) by subtracting the value for 100 g mass vertical position in a resting position (See step m) from the value in a flexed position (See step o) Record your data in Table 3-8.

t. Measure the magnitude of the horizontal displacement (cm) of the 100 g mass by measuring between mark Mass_1 and Mass_2. Record your data in Table 3-8.

Use Pythagoras theorem to calculate the magnitude of the resultant displacement of the 100 g mass. Record your data in

u. Table 3-9.

Calculate the ratio between the resultant displacements of the 100 g mass and the GC displacement. Record your results in

1.24. Table 3-9.

1.25. Calculate the velocity of the GC and the 100 g mass resultant displacements. Assume movement time is 1 second. Record your results in Table 3-10.

BB PROXIMAL INSERTION

1.26. Move the spring scale to connect at the proximal connector so the gastrocnemius (GC) insertion point is at the most proximal point.

1.27. Repeat steps 1.21-1.25 and add data to appropriate tables.

Table 3-8 Displacements of the resistance load moved by the LEG model. Displacement magnitudes (cm) are reported for the Gastrocnemius (GC) insertion point and the 100 g mass, in the vertical, horizontal, and resultant directions. These are reported for the proximal and distal GC insertion points.

	GC Vertical Displacement (cm)	GC Horizontal Displacement (cm)	GC Resultant Displacement (cm)
GC Proximal Insertion (EA1)			
GC Distal Insertion (EA2)			
	100 g Vertical Displacement (cm)	100 g Horizontal Displacement (cm)	100 g Resultant Displacement (cm)
GC Proximal Insertion (EA1)			
GC Distal Insertion (EA2)			

Table 3-9 Resultant displacement magnitudes (cm) for the Gastrocnemius (GC) insertion point and the 100 g mass, and their ratios are reported for the proximal and distal GC insertion points.

	GC Resultant Displacement (cm)	100 g Resultant Displacement (cm)	Ratio of Displacement (mass:GC)
GC Proximal Insertion (EA1)			
GC Distal Insertion (EA2)			

Table 3-10 Velocity (cm/s) for the Gastrocnemius (GC) insertion point and the 100 g mass, are reported for the proximal and distal GC insertion points.

	GC Velocity(cm/s)	100 g mass Velocity (cm/s)
GC Proximal Insertion (EA1)		
GC Distal Insertion (EA2)		

Post Lab Questions

We will conclude lab with a guided group discussion on the data your group, and section collected. Please take notes on this discussion below within the relevant question areas.

Mechanical Advantage

Which model (upper or lower limb) demonstrates greater mechanical advantage (Review and reference data from Table 3-2 + Table 3-7)?

How was this demonstrated when reviewing Fe data for holding a 100 g mass (Review and reference data from Table 3-1 + Table 3-6)?

Distance / Speed Advantage

Which model (upper or lower limb) demonstrates greater advantage for displacement (Review and reference data from Table 3-4 +

Table 3-9)?

How was this demonstrated when reviewing Fe data for holding a 100 g mass (Review Table 3-5 + Table 3-10)?

Hypothesis

When reviewing your group's data, does is support your group's hypothesis? Please provide reasoning to support your answer

Is your hypothesis supported?	
Reasoning	

When reviewing your section's data, does is support your group's hypothesis? Please provide reasoning to support your answer

Is your hypothesis supported?	
Reasoning	

Module 3 Post Lab Activity

Post-Lab Checklist:

- [ ] Document and submit completed procedure and post lab questions (Upload completed procedure page 3:1-3:11)
- [ ] Complete Abstract Writing Assignment (Group Assignment – details below)
- [ ] Complete Group Writing Assignment Submission Form

Group Introduction Writing Assignment:

This week you will work with your assigned group to prepare an abstract for the experiment you conducted for Module 3.

Is there a special format for our lab reports?

Yes, there is a lab report template which is required. Your submission will be returned and receive late penalty deductions if you fail to use the template. You can access the template for your introduction submission here or on your canvas page.

When citating relevant sources in your lab reports, you will need to use IEEE citation style. IEEE in-text citations consist of numbers provided in square brackets, which correspond to the appropriate sources in the reference list at the end of the paper. Please review the IEEE Reference Guide on their website.

How do I get an A grade?

To get an A grade your paper will need to meet most of the "Excellent" criteria in your rubric. There is an A standard abstract available for you to review on Canvas.

Please review your rubric provided below as you prepare your lab report abstract.

Can I get feedback on my group's paper before submission?

Yes! Please come to office hours, your instructional team would be delighted to answer specific questions and once you have completed your paper review your rubric and paper self-assessment.

Abstract Rubric:

Content	Poor	Developing	Average	Adequate	Excellent
Grammar, Spelling and Formatting	Clearly not proofread, is >50% away from word count	Several errors, is >20% away from word count	A few errors, is >20% away from word count	Less than 2 errors appropriate length	Correct grammar and spelling, legible text, headings, and sub-headings used
Abstract Structure	Vague, disorganized, confusing. Missing >2 components of the abstract.	Too little/too much or unnecessary info. Does not flow. Missing >1 components of the abstract.	Includes big picture information but could flow better. May be missing >1 components of the abstract.	Concise but informative. May be missing one component of the abstract.	Reader gets main ideas without reading full paper. Includes important quantitative results. Presents all components of the abstract.
Background	No Background	Vague, background not relevant to topic	Doesn't link background information to experiment	Concise introduction, appropriate length, related to experiment	Concise introduction with relevant information pertinent to experiment. Real world applications stated
Methods	Doesn't describe the research plan	Vague statement on research plan	Describes the research plan, not specific enough/too technical	Appropriate length and description of research plan	Appropriate length description of research plan with concise writing
Results	Doesn't include results	Vague Results	Describes results still vague/no data provided	Data provided, results described, connects to methods	Concise description of results with some insights to discussion. Related to methods. Provides important quantitative results.
Conclusion	Doesn't include conclusion	Vague conclusion/ platitude	Relates results to experiment goals. Lacks broader understanding of results	Appropriate description of results with relation to experiment.	Concise description of results with appropriate relationships to background/experiment/ broader impacts

Module 4 Bioimaging Introduction

Pre Lab-Review

Pre-Lab Checklist:

- **Read:** Ch 2 from Atlas of Ultrasound-Guided Procedures in Interventional Pain Management "The Basics of Ultrasound" by Chan & Perlas.
  V. Chan, and P. Anahi, "Basics of ultrasound imaging." in *Atlas of ultrasound-guided procedures in interventional pain management*. Narouze, S. Ed. New York, NY, Springer, 2011. 13-19. https://doi-org.ezproxy.lib.ou.edu/10.1007/978-1-4419-1681-5_2
- **Submit** Pre-Lab 4 (Complete Quiz on Canvas)

Pre-Lab 4: Bioimaging Introduction

Introduction to Ultrasound & Phantoms

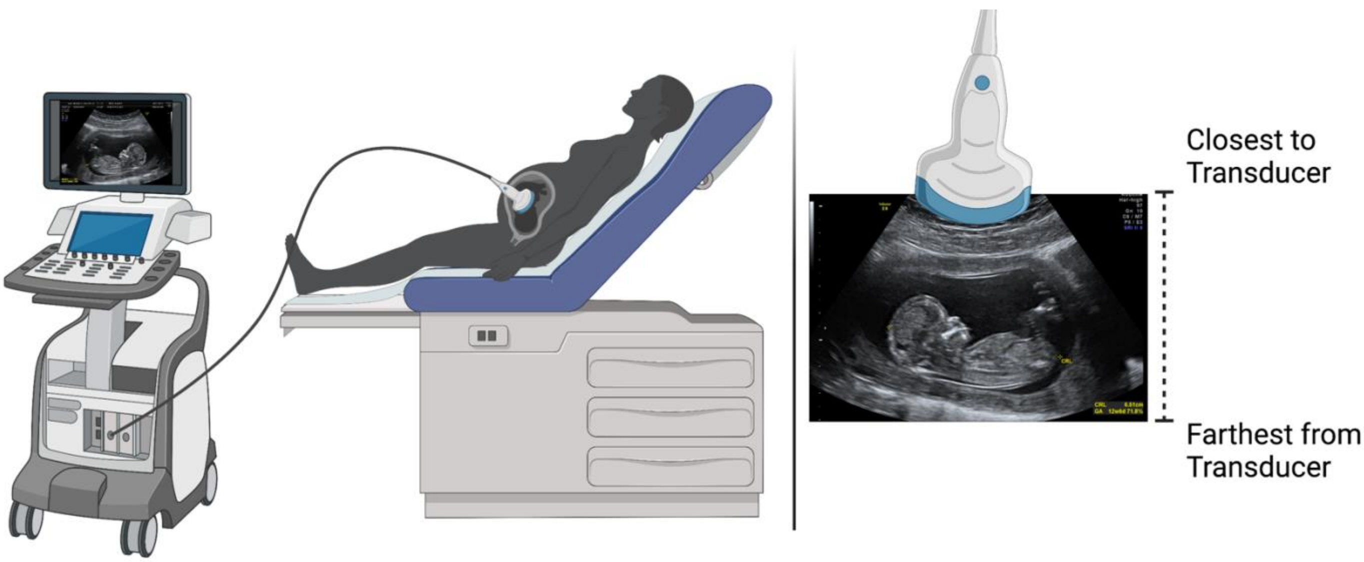


Figure 4-1 Schematic of pregnant person, receiving an ultrasound, and resulting image. Transducer location relative to image produced is also illustrated. *Created with BioRender.com*

Transducer Orientation: Each image represents a slice through the patient. The slice is oriented in a plane that is parallel to the long axis and of the transducer. As shown in Figure 4-1 the top of the image is shallowest or closest to the transducer, and the bottom of the image is deepest or farthest from the transducer.

An *imaging phantom* is a model or device that is used to mimic natural tissue. They are used for testing and calibrating imaging devices and training users on imaging devices. In this lab, you will use a relatively simple ultrasound phantom that contains a branched "blood vessel" which contains a red liquid. This phantom can be used to practice venipuncture.

Question 1:

What relationship does acoustic impedance have with material density and speed of sound?

Question 2:

Describe at three factors that would affect the echo of the ultrasound waves being reflected to the transducer.

1	
2	
3	

Question 3:

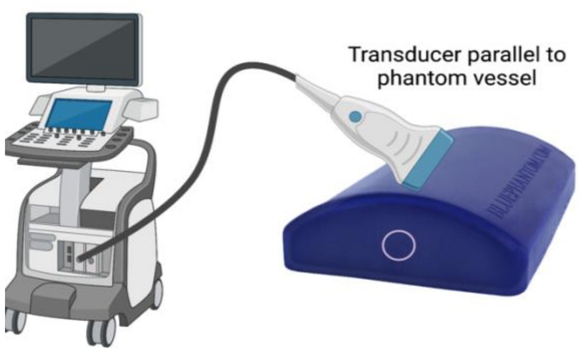


Figure 4-2 Schematic of phantom being images with the transducer viewing the vessel in the longitudinal view (orientated parallel to the phantom vessel). *Created in Biorender.com*

Imagine a “blood vessel” in the shape of a simple cylinder running in parallel through the long dimension of blue phantom below. Predict, via a simple sketch, what you predict the image of the blood vessel would look like if it was acquired from the ultrasound with the transducer oriented in parallel (Figure 4-2).

Draw another sketch for the transverse view (rotating the transducer 90˚ so that it is perpendicular to the long axis).

Please upload a copy of this sketches on the next page to your canvas quiz to show your work.

Question 3 sketches:

Parallel Transducer (Longitudinal View)	**Perpendicular Transducer (Transverse View)**

Question 4:

Based on your predictions in Question 3, what angle is best for inserting a needle when using ultrasound to visualize? Why is this?

Which angle is best?	
Why?	

Module 4 Lab Procedure

Introduction:

Ultrasound, also known as medical sonography or ultrasonography, uses high frequency *sound waves* to create images of the inside of the body. Ultrasound machines send sound waves into the imaged specimen and convert the returning sound reflections, echoes, and changes in frequency into a picture. It is non-invasive, and safe, and relatively inexpensive. In this lab, you will learn the basic use and operational principles behind ultrasound (US) imaging.

Learning Objectives

1. Operate and compare US probes for high resolution or deep structure imaging.
2. Demonstrate the ability to adjust US settings such as gain, power and depth.
3. Demonstrate the ability to operate an US probe to identify fluid space.
4. Demonstrate the ability to take quantitative US measurements.

Materials

Ultrasound Machine	Blue Phantom	Syringe
Acoustic gel	Smart phone Camera	21 G. Needle
	Ruler	

Important Terms

Gain	
Power	
Depth	
Frequency	
Transverse	
Longitudinal	
Diameter	
Cross Sectional Area	
Artifacts	

Safety:

Do not poke yourself with a needle. Do not recap needles. When you are finished place them in sharps container.

Procedure

There are several ultrasound machines in the lab. Each machine has a quick tips manual that points out basic buttons and features which may help you complete this lab procedure. You can access the quick tips manual here or on your canvas page.

PREDICTING AND IMAGING THE PHANTOM

Each person in your group should take turns using the probe to image the phantom.

1.1. There is a branched "blood vessel" inside the phantom that runs parallel with the long edge of the phantom. Predict and sketch a *transverse* view of your phantom in the space below.

1.2. Now make a scan with the probe *transverse* to the phantom (and the leading edge pointing toward the long edge of the phantom that is furthest from you). Move the probe until the probe image is perpendicular to the vein.

   a. Adjust depth so that bottom of the phantom is at the bottom of the image.
   b. Adjust the focus to optimize the image of the vessel inside the phantom.
   c. Adjust the gain so the *anechoic* structures (e.g., fluids) are black.
   d. Take a "screen shot" of the ultrasound and add it below. You may do this with your smart phone.

DISCUSSION POINTS:

How can you identify the bottom of the phantom?

How can you tell when you have obtained a cross-section perfectly perpendicular to the long axis of the vein?

1.3. Compare your sketch to your observed image and make notes of your observations.

Transverse View Sketch	Transverse View Photo
Notes on sketch and photo comparison:	

1.4. Now predict and sketch a *longitudinal* view of your phantom in the space below.

1.5. Now make a scan with the *longitudinal* to the phantom, meaning the leading edge is pointing along the long axis of the phantom.

a. Rotate the probe so that the beam is perfectly parallel with both the shallow and deep vessel interfaces.
b. Adjust depth focus and gain if required.
c. Take a “screen shot” of the ultrasound and add it below. You may do this with your smart phone.

DISCUSSION POINT:

How do you know that you have the correct orientation?

1.6. Compare your sketch to your observed image and make notes of your observations.

Longitudinal View Sketch	Longitudinal View Photo
Notes on sketch and photo comparison:	

1.7. Follow the blood vessel along the entire length of the phantom to find the area where it branches. **Have each person attempt this.** Record the position of the blood vessel branch and include a screenshot below:

Branch Location (cm)		Branch Ultrasound Photo
Distance from long edge		
Distance from short edge		

ULTRASOUND GUIDED NEEDLE INSERTION

1.8. Use ultrasound scanning to guide a needle into the “blood vessel” in the phantom

a. **IMPORTANT**: Do NOT twist or bend the needle around in the phantom! Treat it as if it were an actual patient. If you miss the vein, remove the needle, and reinsert into the phantom.

b. Insert the syringe into the vein using both longitudinal and transverse imaging for guidance. Add notes on both below:

Navigation with transverse view		Navigation with longitudinal view	
Pros	**Cons**	**Pros**	**Cons**
Which method is better/easier and why:			

1.9. When the syringe is inside the blood vessel draw out approximately 1 ml of fluid. Leave the syringe in the phantom with the fluid in the syringe.

1.10. Next dispense the fluid back into the blood vessel. Observe what is happening in the image.

DISCUSSION POINT:

Why can you see the moving fluid when you can't see the stationary fluid?

1.11. Make sure to place the used needle in the yellow sharps container.

QUANTITATIVE ULTRASOUND MEASUREMENTS

1.12. Using guidance from your quick tips manual, measure the diameter and cross-sectional area of the blood vessel

a. Freeze an image of the transverse view of the cross section of your blood vessel.

b. Use the measure feature to make a measurement across the diameter of the vessel. Repeat each measurement at least three times (make sure each team member takes one measurement). Report these measurements below.

	Operator Initials	Blood Vessel Diameter (cm)	Blood Vessel Cross Sectional Area (cm^2)
1			
2			
3			
4			
5			

COMPARE HIGH AND LOW FREQUENCY ULTRASOUND PROBES

1.13. Using the Toshiba US machine, compare low (3.75 MHz) and high (7.5-10 MHz) frequency images of the transverse view of the phantom blood vessel.

   a. Compare the low frequency probe to the high frequency probe.
      - Take a screen shot of both and include below

Low Frequency Probe Photo	High Frequency Probe Photo
Notes on high / low frequency probe comparison:	

FREE PLAY

- Feel free to try out the ultrasound on your arm. Try to image an actual blood vessel. Try to image the muscles in your forearm.
- Switch ultrasounds with another group to try get comfortable with the different ultrasound machines in the lab.

CLEAN UP

- Make sure you wipe up any acoustic gel off the phantom and probes. Wipe the phantom with a paper towel and give it a quick rinse in the sink. Afterwards make sure it is dry before putting back in its container.
- Clean up the rest of your materials.
   - Make sure sharps (used needles) go in the yellow sharps container.
- At the end of lab make sure the ultrasound is turned off and the probe is stored in its appropriate spot.

Module 4 Post Lab Activity

Post-Lab Checklist:

- [ ] Document and submit completed procedure and post lab questions (Upload completed procedure page 4:1-4:6)

Post Lab Questions

We will conclude lab with a guided group discussion on the data your group, and section collected. Please take notes on this discussion below within the relevant question areas.

Question 1:

Why would a clinician or researcher select a high-frequency probe over a low frequency probe? What do you lose with the high-frequency probe?

Question 2:

Please review and compare your pre-lab predictions for the longitudinal and transverse view of the phantom vessel to the images you captured in lab?

Question 3:

Explain three different artifacts or image defects that can be observed in Ultrasound Imaging. Explain how to avoid or eliminate them.

	Artifact / image defect	How to avoid or eliminate it:
1		
2		
3		

Module 5 Factors Influencing Force Production

Pre Lab-Review

Pre-Lab Checklist:

- [ ] **Read:** Abe et al., 2015 "Associations between handgrip strength and ultrasound-measured muscle thickness".
Abe T, Counts BR, Barnett BE, Dankel SJ, Lee K, Loenneke JP. "Associations between handgrip strength and ultrasound-measured muscle thickness of the hand and forearm in young men and women." *Ultrasound Med & Biol,* Vol. 41, no. 8, pp. 2125-30, Aug 2015, https://doi.org/10.1016/j.ultrasmedbio.2015.04.004.
- [ ] **Watch:** An introductory YouTube video "The Technology That Changed Neurology: Electromyography explained".
Sivakumar M, USA, *The Technology That Changed Neurology: Electromyography explained,* (Feb, 21, 2022). Accessed: Dec 23, 2022/ [Online Video]. Available: https://youtu.be/HBj-8EagPi8
- [ ] **Submit** Pre-Lab 4 (Complete Quiz on Canvas)

Pre-Lab 5: Electromyography Introduction

Motor units are defined as a motor neuron and all the muscle fibers that the motor neuron innervates. An action potential (AP) in a human motor neuron always causes an action potential in all the muscle fibers of the motor unit. As a matter of fact, humans generally do not send just one AP at a time down a motoneuron. Instead, a train of APs is sent – enough to induce *tetany* (the sustained fusion of individual muscle twitches) in the muscle fibers of the motor units.

Most human skeletal muscles are composed of hundreds of motor units. When a skeletal muscle is called on to perform mechanical work, the number of motor units in the muscle activated by the brain is proportional to the amount of work to be done by the muscle; the greater the amount of work to be done, the greater number of motor units are excited. Thus, more motor units are simultaneously excited when a skeletal muscle lifts 20 kg than when the same muscle lifts 5 kg.

In this lab, you will examine motor unit recruitment and skeletal muscle force by combining *electromyography* and *dynamometry*. When a motor unit is activated, the component muscle fibers generate and conduct their own electrical impulses, which causes the fibers to contract. Although the electrical impulse generated and conducted by each fiber is very weak (less than 100 μV), many fibers conducting simultaneously induces voltage differences in the overlying skin which are large enough to be detected by a pair of surface electrodes. The detection, amplification, and recording of changes in the skin voltage produced by underlying skeletal muscle contraction is called *electromyography*.

Before completing these prelab questions, please read the journal article (Abe et al., 2015) and watch the video (Sivakumar (2022)), both linked in your checklist.

Question 1:

What is a motor unit?

Question 2:

Describe three applications for Electromyography.

1	
2	
3	

Question 3:

Abe et al., 2015 measured muscle thickness of the anterior forearm with a B-mode ultrasound (Aloka SSD-550). What frequency probe was used in this study.

	Hz

Question 4:

Abe et al., 2015 ensured experimental reliability and validity by measuring muscle thickness of the anterior forearm at a specific location. Describe the exact location used for muscle thickness measurement.

Location:	

Question 5:

Write a measurable hypothesis related to the muscle force during a maximal gripping exercise for dominant vs non-dominant arms.

Independent Variable(s):	
Dependent Variable(s):	
Control Variable(s):	
Hypothesis:	

How will you statistically evaluate this hypothesis?

Module 5 Lab Procedure

Introduction:

In this lab, you will examine motor unit recruitment, force production and muscle thickness by combining electromyography, ultrasound, and dynamometry. When a motor unit is activated, the component muscle fibers generate and conduct their own electrical impulses, which causes the fibers to contract. The detection, amplification, and recording of changes in the skin voltage produced by underlying skeletal muscle contraction is called electromyography.

Learning Objectives

1. Demonstrate the ability to measure forearm muscle thickness, muscle excitation, grip strength & forearm circumference.
2. Compare the factors influencing force production between a participant's dominant and non-dominant arms

Materials

Ultrasound Machine	iWork TA System (IXTA)	Disposable electrodes
Acoustic gel	iWire-B3G EMG cable	Alcohol swabs
Metric Tape	iWire-B3G electrode lead wires	
	FT-220 Hand Dynamometer	

Important Terms

Electromyography	
Dynamometer	
Head of the radius	
Styloid Process	
Motor Unit	
Hand dominance	
Lateral	
Integral	

Safety:

Make sure students with sensitive skin or allergies to alcohol swabs, electrode gel or Band-Aids are not the research participant for these experiments.

[1] Experimental Setup & Participant Preparation

PRELIMINARY EMG SETUP [Already completed by your instructor]

The iWorks TA system, iWire EMG cable and FT-220 Hand Dynamometer should be setup and ready for use.

A lab laptop will also be setup with the LabScribe software open with the EMG Grip Strength setup loaded.

ELECTRODES

1.1. Insert the red, black, and green electrode lead wires into the matching sockets on the EMG cable.

PARTICIPANT PREPARATION

1.2. Remove all jewelry from the participant's wrists. Ensure participant is wearing a t-shirt of that there is access to the arm from the wrist to above the elbow.

1.3. Identify the participant's dominant wrist by asking which hand they use most often for activities of daily living such as writing.

1.4. _To prepare the EMG electrode sites:_ Use an alcohol swab to clean and scrub three regions on the inside of the subject's dominant forearm where the electrodes will be placed (Figure 5-1). One area is near the wrist, the second is in the middle of the forearm, and the third area is about 2 inches from the elbow.

1.5. _To identify the location of Ultrasound measurement:_ Measure the distance between the styloid process and the head of the radius.

   a. Make a mark with a sharpie marker 30% from the head of the radius.

   b. With a metric tape measure the circumference of the forearm at this location. Place this data in Tables 1 and 2.

1.6. Repeat Steps 1.4 and 1.5 for the participant's non-dominant arm.

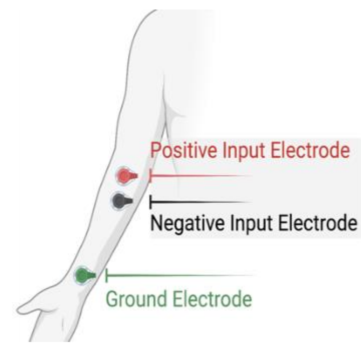


Figure 5-1 Electromyography sites for positive, negative, and ground electrode on the anterior forearm
Created in Biorender.com

HYPOTHESIS DEVELOPMENT

Today we will measure EMG Excitation (mV), Grip Strength (PSI), and forearm muscle thickness (cm) in both the dominant and non-dominant hand of college students.

What is your Hypothesis for this experiment.

Independent Variable(s)	
Dependent Variable(s):	EMG Excitation, Grip Strength, Muscle Thickness
Control Variable(s):	
Hypothesis:	

[2] EMG & Grip Strength Data Collection

EMG Excitation and Force

2.1. Ensure all areas have dried before attaching the disposable electrodes.

2.2. Snap the lead wires onto the electrodes as shown in Figure 2. the red “+1” lead is attached to the electrode near the elbow. The black “-1” lead is attached to the electrode in the middle of the forearm. The green “C” lead (the ground) is attached to the electrode on the wrist.

2.3. Ask the participant to sit quietly with their forearm resting on the tabletop, and the hand dynamometer in their hand.

a. Click the preview button (see Figure 5-2) to visualize the forearm EMG and grip strength data. Ask the participant to squeeze the dynamometer and observe the changes to both signals.

2.4. The EMG data required for this experiment will require the participant to squeeze their fist around the dynamometer five times, each contraction should last two seconds, followed by two seconds of relaxation. Each contraction attempt should be maximal.

a. Type “Grip Force-Dominant” in the Mark box to the right of the Mark button.

Click the Record button (see

b. Figure 5-2) to begin the recording; then, press the mark button to mark the beginning of the recording. After the recording is marked, tell the subject to begin squeezing the hand dynamometer and repeat for 5 contractions as described above.

c. In the relaxation period after the last contraction, click the Stop button.

Click the AutoScale button (see

d. Figure 5-2). The recording should look something like **Error! Reference source not found.**.

2.5. Select Save from the file menu (save your files in your class and section folder on the desktop of your assigned laptop).

2.6. Repeat Steps 2.1 to 2.5 for the participant’s non-dominant arm.

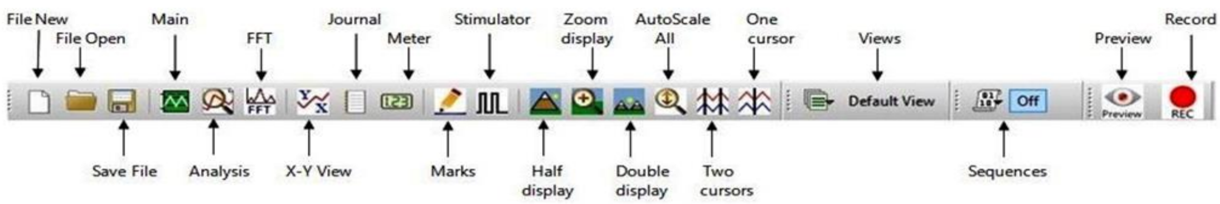


Figure 5-2 LabScribe Toolbar

[3] EMG & Grip Strength Data Analysis

EMG Excitation and Force

3.1. Use the Display Time icons to adjust the Display Time of the Main window to show the progressive muscle contractions of Exercise 1 on the Main window.

3.2. Click on the Analysis window icon in the toolbar (Figure 5-3) or select Analysis from the Windows menu to transfer the data displayed in the Main window to the Analysis window. You can use the Main icon to return to the previous view.

3.3. Look at the Function Table that is above the uppermost channel displayed in the Analysis window. The mathematical functions, Abs. Int., V2-V1, and T2-T1 should appear in this table. The values for Abs. Int., V2-V1, and T2-T1 on each channel are seen in the table across the top margin of each channel.

3.4. Once the cursors are placed in the correct positions for measuring the absolute integrals under the muscle contraction and the corresponding EMG excitation, the values for the integrals can be recorded in your data tables. Pay attention to T2-T1 remember the contraction period should be only two seconds.

3.5. Use the mouse to click on and drag the cursors (vertical red lines) to the beginning and end of the first muscle contraction (Figure 5-3). The values for Abs. Int. on the EMG and Muscle channels are the relative amount of the electrical excitation causing the contraction and relative strength of the muscle, respectively. Record the values for these integrals in Table 5-1 and Table 5-2.

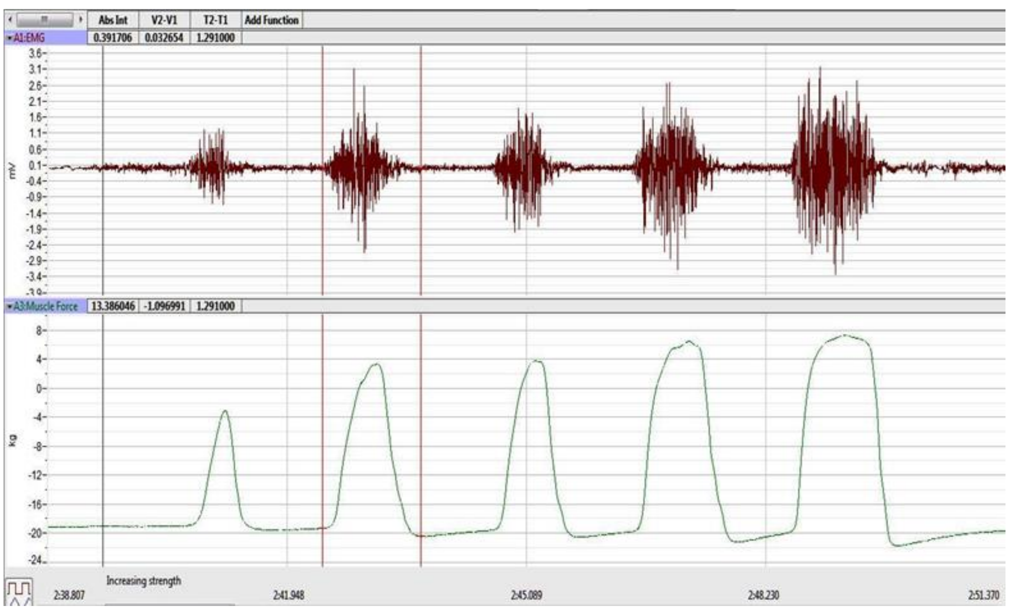


Figure 5-3 The EMG and muscle force recordings displayed in the Analysis window. The cursors are placed on the margins of the 2nd muscle contraction and the absolute integral function is used to measure the area under the EMG spikes and the area under the force recording.

[4] Ultrasound Procedure

There are several ultrasound machines in the lab. Each machine has a quick tips manual that points out basic buttons and features which may help you complete this lab procedure.

Forearm Muscle Thickness

Based on the procedure outlined in Abe et al. 2014. It is recommended you read the muscle thickness measurement of this paper before proceeding. (It is linked in your pre-lab and on Canvas)

4.1. Ask your participant to stand quietly with their knees extended and weight evenly distributed on both legs. Both elbows should be extended and relaxed.

4.2. Prepare your transducer with acoustic imaging gel.

4.3. At your marked location (Step 1.5) visualize the forearm with a transverse view of the forearm muscles. Sample images of this area of the forearm are shown in Figure 1 of Abe et al., 2014.

4.4. Using guidance from your quick tips use your ultrasound machine to Measure the Forearm Muscle Thickness to the ulna as illustrated in Figure 1 of Abe et al., 2014.

4.5. Repeat steps 4.3 and 4.4, four times to collect five measurements on both the dominant and non-dominant arms. Enter this data in Table 5-1 and Table 5-2.

Table 5-1 EMG Excitation (mV), Relative Muscle Strength (PSI), Muscle Thickness (cm) and Forearm Circumference in the Dominant Forearm.

DOMINANT ARM	Absolute Int. of EMG Excitation	Absolute Int. Under Force curve	Muscle Thickness (cm)	Forearm Circumference
1				
2				
3				
4				
5				
AVG				
STDEV				

Table 5-2 EMG Excitation (mV), Relative Muscle Strength (PSI), Muscle Thickness (cm) and Forearm Circumference in the Non-Dominant Forearm.

NON-DOMINANT ARM	Absolute Int. of EMG Excitation	Absolute Int. Under Force curve	Muscle Thickness (cm)	Forearm Circumference (cm)
1				
2				
3				
4				
5				
AVG				
STDEV				

Post Lab Questions

We will conclude lab with a guided group discussion on the data your group, and section collected. Please take notes on this discussion below within the relevant question areas.

Hypothesis

When reviewing your group's data, does is support your group's hypothesis? Please provide reasoning to support your answer

Is your hypothesis supported?	
Reasoning	

Data Validity

Is the data your group collected valid? Please provide reasoning to support your answer

Is your data valid?	
Reasoning	

Data Reliability

Is the data your group collected reliable? Please provide reasoning to support your answer

Is your data valid?	
Reasoning	

Module 5 Post Lab Activity

Post-Lab Checklist:

- [ ] Document and submit completed procedure and post lab questions (Upload completed procedure page 5:1-5:6)
- [ ] Complete Methods Writing Assignment (Group Assignment – details below)
- [ ] Complete Group Writing Assignment Submission Form

Group Methods Writing Assignment:

This week you will work with your assigned group to prepare a lab report methods section for the experiment you conducted for Module 5.

Is there a special format for our lab reports?

Yes, there is a lab report template which is required. Your submission will be returned and receive late penalty deductions if you fail to use the template. You can access the template for your methods writing submission here or on your canvas page.

When citing relevant sources in your lab reports, you will need to use IEEE citation style. IEEE in-text citations consist of numbers provided in square brackets, which correspond to the appropriate sources in the reference list at the end of the paper. Please review the IEEE Reference Guide on their website.

How do I get an A grade?

To get an A grade your paper will need to meet most of the “Excellent” criteria in your rubric. There is an A standard abstract available for you to review on Canvas.

Please review your rubric provided below as you prepare your lab report abstract.

Can I get feedback on my group’s paper before submission?

Yes! Please come to office hours, your instructional team would be delighted to answer specific questions and once you have completed your paper review your rubric and paper self-assessment.

Methods Rubric:

RUBRIC	Missing	Poor	Developing	Average	Adequate	Excellent
[1] Experimental design	Not provided	Briefly mentioned, unclear.	States the experimental parameters used, but little or no explanation of why they were chosen. Most participant or specimen demographics are missing.	Appropriate design but may not have attempted to collect appropriate data for full assessment of hypothesis. Most participant or specimen demographics are detailed clearly.	Describes how/why experimental parameters were selected, may be missing appropriate controls. All participant or specimen demographics are detailed clearly.	Provides clear and concise reasoning for how/why experimental parameters were selected; Appropriate controls included. All participant or specimen demographics are detailed clearly and concisely
[2] Experimental Setup	Not provided	Briefly mentioned, no details	Too vague, may not say how many trials performed. Most data collection tools are missing	Basic summary of how experiments were performed, may omit some specific details, includes number of trials. Most data collection tools are identified.	Summarizes all details for creating experimental conditions, including description of all independent variables used and number of trials. All data collection tools are identified.	All key details for creating experimental conditions clearly and concisely included such that a skilled researcher could replicate the experiment, includes a diagram or table summarizing experimental conditions if necessary. All data collection tools are identified. Manufacturer details and software versions are specified correctly.
[3] Measurement & Analysis	Not provided	May be incorrect or only briefly mentioned	Data analysis procedures are described. Most required elements are missing. Incorrect explanation, missing info, experiment never repeated	Data analysis procedures are described clearly. Most required elements are included. Simply states statistics tests used; experiments repeated at least twice	Data analysis procedures are described clearly. Most required elements are included. States how/why statistics were chosen; experiments repeated appropriately.	Data analysis procedures are described clearly and succinctly. All required elements are included [key steps of data processing, calculation of variables]. States how/why statistics were chosen, repeated experiments appropriately, chose relevant biomechanical parameters
Grammar, Spelling and Formatting	Clearly not proofread, is >50% away from word count	Several errors, is >20% away from word count		A few errors, is >20% away from word count	Less than 2 errors appropriate length	Correct grammar and spelling, legible text, headings, and sub-headings used

Module 6 Uniaxial Testing & Anisotropy

Pre Lab-Review

Pre-Lab Checklist:

- [ ] **Read:** Ch 13, Sections 13.11-13.13 from Fundamentals of Biomechanics "Stress & Strain" by Özkaya et al., 2017.
Özkaya, N., Leger, D., Goldsheyder, D., Nordin, M. "Stress & Strain." in *Fundamentals of Biomechanics*. Switzerland, Springer, 2017. 287-316. https://doi-org.ezproxy.lib.ou.edu/10.1007/978-3-319-44738-4_13
- [ ] **Submit** Pre-Lab 6 (Complete Quiz on Canvas)

Pre-Lab 6: Introduction to Uniaxial Testing

The uniaxial test is one of the most widely used tests to measure the mechanical properties of materials. The concepts of stress and strain are essential to understanding the results of the test. The purpose of the tension test is to measure the stress-strain response of a material. This is accomplished by subjecting a material of known geometry to increasing axial elongation until it breaks. The result of such test is usually reported in the form of a stress-strain diagram (Figure 6-1Figure 6-1 Typical Stress-Strain curve of ductile material).

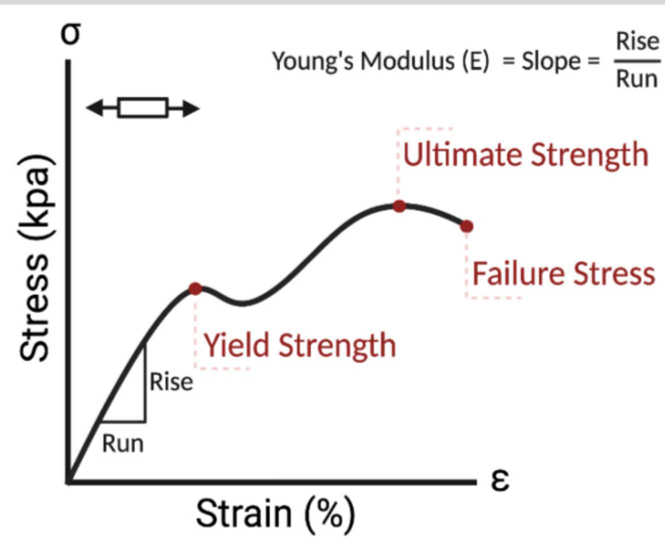


Figure 6-1 Typical Stress-Strain curve of ductile material. Created with Biorender.com

The *stress-strain* diagram is usually plotted with the stress (σ) in the vertical axis and the strain (ε) in the horizontal axis. The origin corresponds to the unloaded specimen. Initially, for this material, between the origin and the yield point, the relation between stress and strain is linear. The slope of this line is called *Young's modulus* or modulus of elasticity. Therefore, in this linear elastic region we have $\sigma = E\varepsilon$.

Yielding is caused by a slight increase in stress above the elastic limit, at the point of yield strength. Deformation beyond this point is called plastic deformation. The material will no longer return to its original geometry when it has undergone plastic deformation.

The *ultimate strength* is the highest amount of stress the material can withstand. Past the ultimate stress, some materials exhibit necking. *Necking* is due to a decrease in the cross-sectional area in a localized region of the material (rather than throughout the entire length). In this region, the stress keeps dropping until the specimen reaches failure. *Failure stress* is the amount of stress right at fracture.

Question 1:

Read through the Module 6 Lab Procedure and draft the following hypotheses.

Write a measurable hypothesis related to the material orientation for each material.

Independent Variable(s):	Material Orientation for Glove; Vertical Vs Horizontal	Material Orientation for Adhesive Wrap; Vertical Vs Horizontal
Dependent Variable(s):		
Control Variable(s):		
Hypothesis:		

Write a measurable hypothesis related to the material for each material.

Independent Variable(s):	Material: Glove Vs Adhesive Wrap
Dependent Variable(s):	
Control Variable(s):	
Hypothesis:	

Question 2:

Using Figure 6-2 to draw a sketch of the predicted stress-strain curves for the samples (the glove and adhesive wrap). The values on the axes do not matter as much as the shape of the curves relative to each other.

Please upload a copy of these sketches to your canvas quiz to show your work.

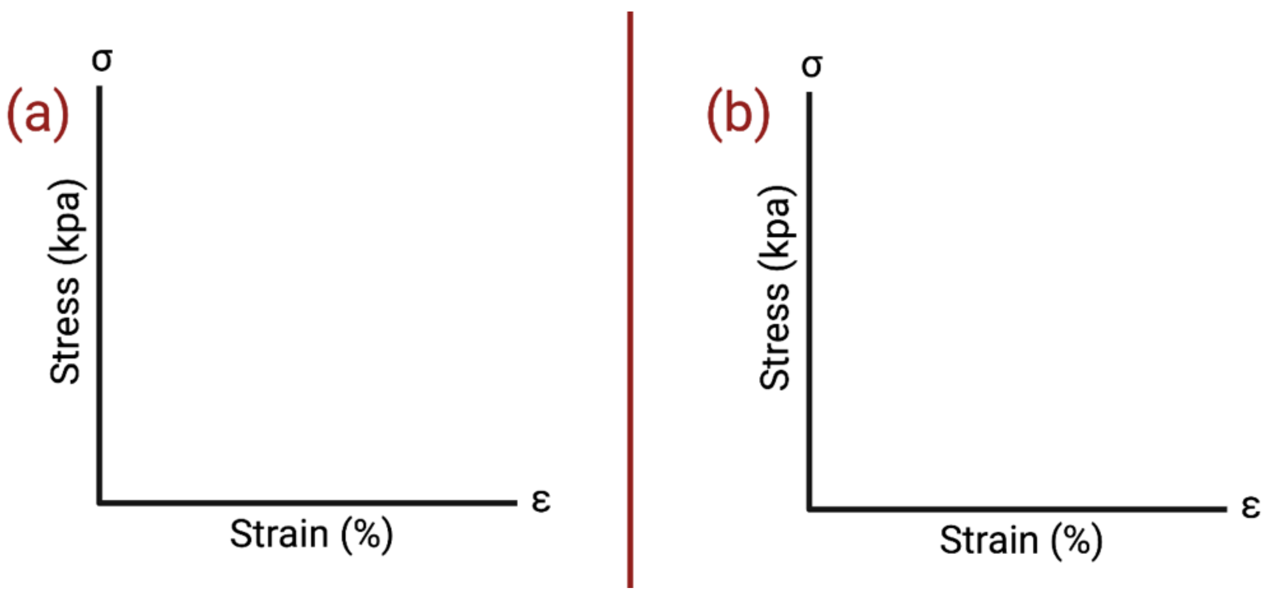


Figure 6-2 Illustration of Stress V Strain curve for a glove material (a) and an adhesive wrap material (b)

Question 3:

You are going to calculate the ultimate stress of the glove material. The sample has a known width of ~20.0 mm and a variable thickness. However, the glove manufacturer reports a material thickness in a range, depending on the part of the glove. If you find that the ultimate load is 8.0 N and you assume a thickness of 0.12 mm, what is the largest possible % error in your calculation? Show your calculations below.

Please upload a copy of this page to your canvas quiz to show your work.

Table 6-1 Maximum and minimum glove thickness values for finger, palm, and cuff locations.

Glove Location	**Minimum thickness (mm)**	**Maximum thickness (mm)**
Finger	0.11	0.17
Palm	0.09	0.15
Cuff	0.07	0.13

Module 6 Lab Procedure

Introduction:

The *uniaxial test* is one of the most widely used tests to measure the mechanical properties of materials. The concepts of *stress* and *strain* are essential to understanding the results of the test.

The purpose of the *tension test* is to measure the stress-strain response of a material. This is accomplished by subjecting a material of known geometry to increasing axial elongation, often until it breaks. The result of such test is usually reported in the form of a stress-strain diagram.

Learning Objectives

1. Familiarize yourself with common procedures and instrumentation used to conduct uniaxial tensile tests.
2. Determine common stress-strain features, which can be obtained from uniaxial tension tests, including tensile strength, failure stress, and regions of necking.
3. Quantitatively assess the anisotropic properties of a material via uniaxial tensile testing

Materials

Nitrile gloves	Scissors	Nεwtσn TestResources Machine
Self-Adhesive wrap	Dogbone Stencil	Digital Calipers
		Digital Micrometer

Important Terms

Stress	
Strain	
Ultimate Strength	
Failure Stress	
Necking	
Engineering Stress	
Failure	
Uniaxial	
Tension Test	
Tare	

Safety:

- You must always wear safety goggles during this lab. Mechanical testing causes rupture of materials which may become projectiles.
- Always be aware of where you are putting your fingers. There are many opportunities to pinch your fingers in the moving parts and clamps of the machine. Specifically:
  - Pay careful attention when clamping a sample into the fixtures.
  - Tie long hair back and remove any dangly jewelry which can be caught on the machine.

Module 6 Procedure

HYPOTHESIS DEVELOPMENT

Today we perform a Uniaxial Tension Test to determine the mechanical properties of materials. Today you choose your own adventure and pick an independent variable and hypothesis to test.

What is your Hypothesis for this experiment.

Independent Variable(s)	
Dependent Variable(s):	
Control Variable(s):	
Hypothesis:	

MATERIAL PREPARATION

1.1. In accordance with your chosen hypothesis, you will test two sets of material in this experiment. Each set of samples will have three replicates, it is recommended you prepare 4 replicates in case of experimental error; therefore, you will prepare eight total samples. The sets you will use should be chosen from the following list and match your hypothesis:
   a. Glove – horizontal orientation
   b. Glove – vertical orientation
   c. Adhesive wrap – horizontal orientation
   d. Adhesive wrap – vertical orientation

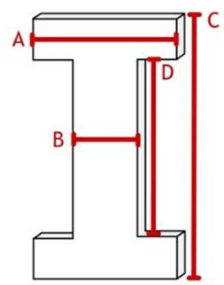
1.2. Each sample should be cut to the same size using the dogbone stencil. The dogbone shape ensures that the sample has the same gauge length, and it also increases the probability that the material will break toward the middle of the sample, rather than near the clamps.

1.3. You will measure the dimensions of your samples and stencil in the next section, please include notes from your instructor demonstration for the use of your calipers and micrometer here:

	Digital Calipers	Digital Micrometer
How to turn on and tare		
How to adjust measurement points		
How to determine sample dimension		

1.4. Measure the dimensions of your dogbone stencil with a digital caliper. These are important to report in the methods section of an experimental report, record them in Table 6-2.

Table 6-2 Dogbone stencil dimensions (mm). Measurements included for thickness, width (large (A) and small (B) areas) and length (large (C) and small (D) areas).

	Thickness (mm)	Width (mm)		Length (mm)	
		A	B	C	D

Measure the width of each sample in the gauge region of the dogbone shape, with digital calipers. (Place these measurements in

1.28. Table 6-4).

Measure the thickness of each sample with a micrometer before testing. Take multiple measurements and use the average thickness for your stress calculations. (Place these measurements in

1.29. Table 6-4).

v. REMINDER NOTES ON MICROMETER USE:

  i. The large knob on the micrometer is a friction drive, it will click when it senses a large amount of resistance, and you should stop turning the drive before you first feel the click. Test this out on some sample materials before taking your measurements.
  ii. The smaller knob is a quick drive, only use this to make large adjustments to the distance, not when you are trying to fine tune the distance on the micrometer.
  iii. Make sure to reset the micrometer between measurements. To do this close the micrometer so the measurement points meet, then hold the on/off button the reset or tare the device.
  iv. Make sure the micrometer is turned off when you are finished with it, to save the battery.

1.30. The make and model information of the micrometer and calipers are important to report in the methods section of an experimental report, record them in Table 6-3.

Table 6-3 Make and model information for measurement tools used in Module 6.

Equipment	Make	Model	Methods text
Metal Ruler (Sample)	Grand Birches Inc	30 cm	30 cm Stainless steel ruler (Grand Birches Inc, CO, USA)
Digital Calipers			
Digital Micrometer			

Table 6-4 Specimen details for material thickness (mm), sample width (mm) and gauge length (mm). Set details for material comparison are highlighted in grey.

Replicate	Sample Thickness (mm)		Sample Width (mm)		Gauge Length (mm)	
	Set 1 [________]	Set 2 [________]	Set 1 [________]	Set 2 [________]	Set 1 [________]	Set 2 [________]
1						
2						
3						
4						
Average						
Standard Deviation						

TEST FRAME SETUP & DATA COLLECTION

1.31. Each person in the group should load (at least) 1 sample into the test frame.

1.32. Turn on the Nεwtσn TestResources control box (green button on the front). See Figure 6-3.

1.33. Open the TestResources software (Newton).

w. For the "Test Engineer" profile, Enter the password (Three-digit number labelled on the computer). See Figure 6-3.

1.34. Set up the test method using the software.

x. Click the Test Management tab and then select the "Basic Tensile Testing" test.

y. The test method parameters are important to report in the methods section of an experimental report, follow the steps below to find and record the test parameters in Table 6-5:

v. Under the Test Management Tab select your chosen test method "Basic Tensile Testing" and click on the edit (pencil) button.

vi. Navigate to the Segments tab using the arrow buttons [→].

vii. Select Channel 1 and click on the edit (pencil) button.

viii. Select the Channels tab: record the test parameters in Table 6-5.

Figure 6-3 Newton TestResources Machine and accompanying computer. Labels show power button, job buttons and Newton

Table 6-5 Basic Tensile Test Parameters used in the Nεwtσn TestResources Software.

Equipment	Control Channel	Test Direction	Test Rate (mm/min)
Nεwtσn TestResources Machine			

1.35. Navigate to the Online tab to begin the test. Verify that the test frame is communicating with the computer by the green circle in the upper right-hand corner next to "Connection".

1.36. Set up the test batches for each set of samples.

z. Click the batch button. Create 2 different batches one for each sample set.
aa. Increase the "No of Specimens" to be the number of replicates you will be running.
bb. Make sure that the Basic Tensile Test-Copy is selected under the dropdown at "Test".
cc. Hit the + icon to add to the list of batches.

1.37. After creating your batches, click the check box next to "Batch" and make sure your batch names are selected.

1.38. Load the first sample into the clamps.

dd. Start by clamping the sample into the top fixture (clamp)
   ix. IMPORTANT: Avoid any non-axial stress on the load cell. That is do not put any bending or twisting force on the load cell (force transducer).
   x. Be careful not to jostle the clamp so much that you exceed the maximum on the load cell (50 lb or ~222 N).
      - Have one group member monitor the load cell reading (Ch. Load) on the Newton software while another member loads the sample.
ee. Use the jog buttons to position the fixtures so that the sample can be clamped on both ends without being stretched. See jog buttons in Figure 6-3.
ff. Ensure that the sample is centered between the top and bottom clamps.
gg. Tighten the clamp to ensure a firm grip on the sample, but not too tight that you damage the sample through compression. Hand tightened is sufficient.
hh. Adjust the fixtures, with the jog buttons, so that the sample is taut, but not exerting a load on the load cell. Use the fine adjustment button for this rather than the jog buttons.

1.39. Once the sample is loaded into the top fixture, tare the load cell so that it is zeroed out.

1.40. Tare the position so that it is zeroed out.

With a digital caliper, measure your gauge length (the distance between your clamps), place these measurements in

1.41. Table 6-4.
1.42. Edit your sample dimensions by double clicking on the dogbone icon next to the specimen label.
   ii. Make sure the specimen precision is increased to the appropriate number of significant figures. Make sure the units are correct (these should be mm not inches).
   jj. Ensure that your batch id matches the sample replicate type you are testing.
1.43. Take a picture of the sample in the clamp and place it in Figure 6-5.
1.44. Click Tare and then click Play (▷) to start the test.
1.45. Take a picture of the sample once the test has ended and place it in Figure 6-5
1.46. Repeat steps 1.38 to 1.45 with the other samples in the set.

DATA ANALYSIS

1.47. You will find your pdf reports and csv files in a folder on the desktop.
   kk. Save these files to a USB for further analysis.
   ll. Extract your dependent variable data from your pdf reports as shown in # and place them in Table 6-6 & Table 6-7.

Figure 6-4 Detailed image showing extraction of data from pdf reports and calculation of Ultimate Tensile Strength and Failure Stress

Table 6-6 Tensile Strength (kPa), for each sample set. Set details are highlighted in grey.

Replicate	Set 1 [________]	Set 2 [________]
1		
2		

3		
4		
Average		
Standard Deviation		

Table 6-7 Failure Stress (kPa), for each sample set. Set details are highlighted in grey.

Replicate	Set 1 [________]	Set 2 [________]
1		
2		
3		
4		
Average		
Standard Deviation		

	Pre Test Image	Post Test Images
Set 1 Replicate 1:		
Set 1 Replicate 2:		
Set 1 Replicate 3:		
Set 1 Replicate 1:		
Set 1 Replicate 2:		
Set 1 Replicate 3:		

Figure 6-5 Images of test samples before and after tensile test.

Module 6 Post Lab Activity

Post-Lab Checklist:

- ☐ Document and submit completed procedure (Upload completed procedure page 6:1-6:7)
- ☐ Complete Results & Discussion Writing Assignment (Group Assignment – details below)
- ☐ Complete Group Writing Assignment Submission Form

Group Results & Discussion Writing Assignment:

Is there a special format for our lab reports?

Yes, there is a lab report template which is required. Your submission will be returned and receive late penalty deductions if you fail to use the template. You can access the template for your results and discussion submission here or on your canvas page.

When citing relevant sources in your lab reports, you will need to use IEEE citation style. IEEE in-text citations consist of numbers provided in square brackets, which correspond to the appropriate sources in the reference list at the end of the paper. Please review the IEEE Reference Guide on their website.

How do I get an A grade?

To get an A grade your paper will need to meet most of the "Excellent" criteria in your rubric. There is an A standard results & discussion section available for you to review on Canvas.

Please review your rubric provided below as you prepare your lab report abstract.

What do we include in the results section?

Please follow your rubric but including the key items below is a great start:

- REQUIRED TABLE:
  - Must Include average and standard deviation data for each dependent variable.
  - Must include p-value for comparison of sample sets.
  - Should not include raw replicate data.
- REQUIRED SUPPORTING TEXT:
  - Each Table & Figure that is provided in your results section needs to be mentioned in the main body text of either your results or discussion section.
- OPTIONAL FIGURE:
  - A figure displaying the stress strain curves for each sample set would be very useful for visual comparison. This could be very useful to helping your discussion.

Can I get feedback on my group's paper before submission?

Yes! Please come to office hours, your instructional team would be delighted to answer specific questions and once you have completed your paper review your rubric and paper self-assessment.

Results & Discussion Rubric

RUBRIC	Missing	Poor	Developing	Average	Adequate	Excellent
Results [1a] *Data Presentation tables & figures*	No data provided	Figures and or tables are not well-designed and have several issues and the choice of data presentation is an inaccurate representation of the data collected and/or data is missing. Figures and or tables do not use space effectively and would benefit from redesign. There are several instances of extra information in the figures or tables. Axes, symbols, legends, etc. are not labeled, have incorrect units, or are missing. Captions are lacking key pieces of information or experimental details.	Figures and or tables have several issues, and the choice of data presentation may not clearly match the hypothesis. Figures and or tables may not use space effectively and would benefit from redesign. There are some instances of extra information in the figures or tables. Axes, symbols, legends, etc. may not be correctly labeled, or have incorrect units, or may be missing. Captions contain some of the information needed to interpret the figure but are missing more than two minor details.	Figures and or tables adequately show the data and are mostly well-designed with a few minor issues. There are a few instances of extra information in the figures or tables. Axes, symbols, legends, etc. are appropriately labeled with correct units with two minor exceptions. Captions contain most of the information needed to interpret the figure but may be missing one or two minor details.	Figures and or tables adequately show the data and are mostly well-designed. Figures and or tables mostly use space in effectively. There may be one or two instances of extra information in the figures or tables. Axes, symbols, legends, etc. are appropriately labeled with correct units with one minor exception. Captions contain the appropriate details for the data presented.	Figures and or tables are well-designed and are the best representation of the data. Figures and or tables use space in the report effectively There is no extra information, titles, coloring, gridlines, or other features in the figures. Tables are concise and do not include extra information such as raw trial data, or t-values. All axes, symbols, legends, etc. are appropriately labeled with correct units. Captions are clear and concise and contain the appropriate details for the data presented.
Results [1b] *Data Presentation text*		None of the figures, diagrams, and tables are referred to in text.	Some of the figures, diagrams, and tables are not referred to in text.	Most figures, diagrams, and tables are referred to in the body of the report text.	All figures, diagrams, and tables are referred to in the body of the report text.	All figures, diagrams, and tables are referred to succinctly in the body of the report text.
Results [2] *Data Validity*	No data provided	Data analysis is incorrect and/or incomplete.	Data analysis is mostly inaccurate with several minor errors.	Data analysis is mostly accurate with two minor errors.	Data analysis is mostly accurate with one minor errors.	Data analysis is accurate and complete. *Data matches the hypothesis presenting the average and standard deviation for each dependent variable across each level of the independent variable. Correct and precise P values for each comparison are also included.*
Discussion [1] *Discusses results*	No data provided	Discussion of data is vague or not present .	Not all data is discussed	Discussion of results is somewhat related to the goals from the introduction	Discusses results in the context of the experimental procedure and experimental goals	Discusses results in the context of the experimental procedure and experimental goals, explains limitations of methods used .
Discussion [2] *Discusses statistics*	No data provided	Discussion of statistics is vague or not present	Incorrect statistical tools used or incorrect statistical interpretation	Correct statistical tools used, limited discussion of statistical meaning	Correct statistical tools used, discussion of statistical meaning of data	Correct statistical tools used, discussion of statistical meaning of data, presents suggestions for improvement of statistical methods
Discussion [3] *Organization*	-	Incomplete	No logical order to the discussion points	Organizational mistakes impact overall understanding of discussion	Some organizational mistakes, such starting a discussion point then finishing the discussion point at later in the report	Discussion follows logical order
Grammar, Spelling and Formatting	Clearly not proofread, inappropriate report length		Several errors, text in figures too small	A few errors, major sections labeled with headings, appropriate report length	Less than 2 errors, headings and sub-headings used	Correct grammar and spelling, legible text, headings, and sub-headings used
References	No references cited		No relevant references cited. references not cited in a consistent format; some references might be from Wikipedia	At least one relevant reference cited. Several missing citations supporting claims.	At least two relevant references cited.	Two or more *relevant* references cited appropriately. All statements requiring citation are cited using IEEE style.

Module 7 Uniaxial Testing of Viscoelastic Material

Pre Lab-Review

Pre-Lab Checklist:

- [ ] **Re-Read:** Ch 13, Sections 13.11-13.13 from Fundamentals of Biomechanics "Stress & Strain" by Özkaya et al., 2017.
  Özkaya, N., Leger, D., Goldsheyder, D., Nordin, M. "Stress & Strain." in *Fundamentals of Biomechanics*. Switzerland, Springer, 2017. 287-316. https://doi-org.ezproxy.lib.ou.edu/10.1007/978-3-319-44738-4_13
- [ ] **Read:** Ch 15, Sections 15.1-15.6 from Fundamentals of Biomechanics "Mechanical Properties of Biological Tissues" by Özkaya et al., 2017.
  Özkaya, N., Leger, D., Goldsheyder, D., Nordin, M. "Mechanical Properties of Biological Tissues." in *Fundamentals of Biomechanics*. Switzerland, Springer, 2017. 361-387. https://doi-org.ezproxy.lib.ou.edu/10.1007/978-3-319-44738-4_15
- [ ] **Submit** Pre-Lab 7 (Complete Quiz on Canvas)

Pre-Lab 7: Uniaxial Testing of Viscoelastic Material

Question 1:

Describe, in your own words, a hysteresis loop for a typical viscoelastic material.

Question 2:

Skin is a composite material. What are the **three main** components of skin **that will affect its mechanical behavior** during testing?

1	
2	
3	

Question 3:

Name three factors, controlled by the mechanical testing device, that will affect the mechanical outcomes of the tissue response?

1	
2	
3	

Question 4:

For a typical viscoelastic material, use Figure 7-1 to draw a typical plot from a stress relaxation test.

Please upload a copy of these sketches to your canvas quiz to show your work.

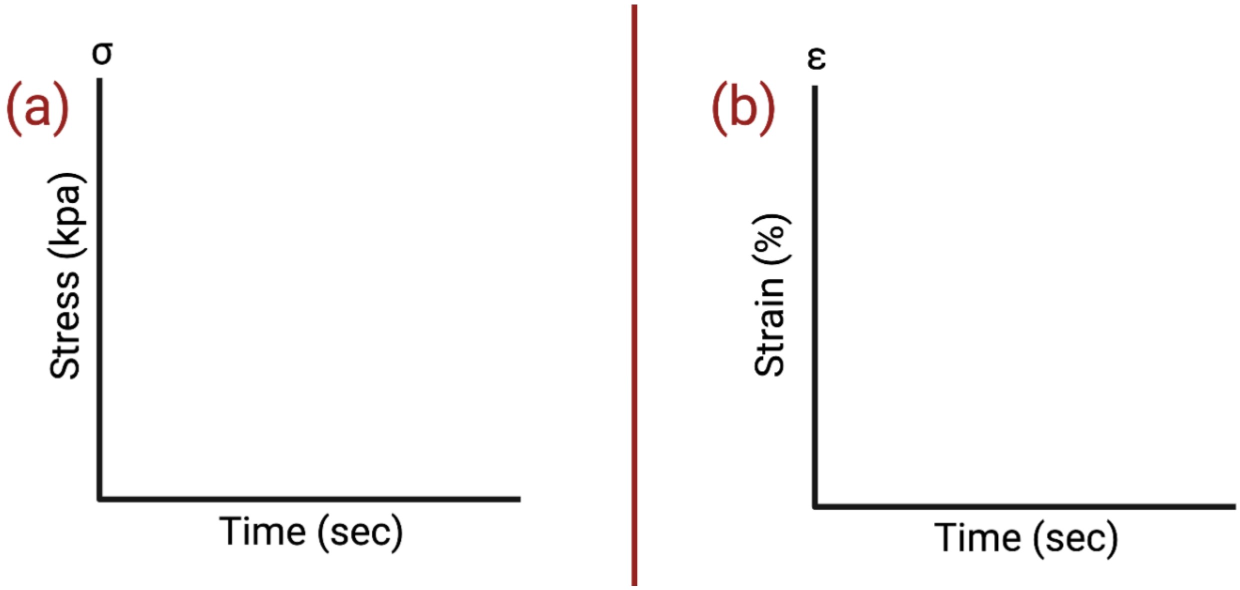


Figure 7-1 Illustration of data from a stress relaxation test for a viscoelastic material. (a) Stress Vs Time curve (b) and a Strain Vs Time curve.

Module 7 Lab Procedure

Introduction:

Viscoelastic materials demonstrate time-dependent material behavior, which is move evident during tests stress-relaxation and creep experiments. The *stress-relaxation test* is completed by instantaneously applying a constant *strain* to a material and observing the *stress* response. are essential to understanding the results of the test. The *creep test* is completed by instantaneously applying a constant *stress* to a material and observing the *strain* response.

Learning Objectives

1. Familiarize yourself with common procedures and instrumentation used to conduct uniaxial tensile tests of viscoelastic materials.
2. Quantitatively assess the viscoelastic properties of a biomaterial via uniaxial tensile testing
3. Experimentally demonstrate the time-dependent nature of a biomaterial's mechanical response

Materials

Chicken leg with skin	Scalpel blades	Paper towels	Nεwtσn TestResources Machine
Specimen Stencil	Scalpel handles	70 % Ethanol	Digital Calipers
PBS Solution	Dissecting scissors	Antibacterial Wipes	Digital Micrometer
Scour Pads	Hemostat	Nitrile Gloves	Stand with clamps
	Absorbent lab pad	Sharps Container	

Important Terms

Viscoelastic	
Hysteresis Loop	
Unloading	
Instantaneously	
Creep	
Time Constant	
Coefficient	
Relationship	

Safety:

- You must always wear safety goggles during this lab. Mechanical testing causes rupture of materials which may become projectiles.
- Always be aware of where you are putting your fingers. There are many opportunities to pinch your fingers in the moving parts and clamps of the machine.
- When handling chicken, or anything contaminated with raw chicken, wear gloves.
- Wipe down your workstation and anything contaminated with raw chicken with 70% ethanol and / or antibacterial wipes

Module 7 Procedure

HYPOTHESIS DEVELOPMENT

Today we perform a Uniaxial Stress Relaxation Test, a Hysteresis Test, and a Creep Test to determine the mechanical properties of chicken skin. We will analyze the data from each test to determine if our chicken skin specimens demonstrate mechanical responses in accordance with our expectations for the time-dependent behavior of typical viscoelastic materials.

What is your Hypothesis for the stress relaxation experiment.

Theoretical Assumption being tested:	
Dependent Variable(s):	Stress
Control Variable(s):	
Hypothesis:	

What is your Hypothesis for the hysteresis experiment.

Theoretical Assumption being tested:	
Dependent Variable(s):	Stress, Hysteresis Loop Area
Control Variable(s):	
Hypothesis:	

What is your Hypothesis for the creep experiment.

Theoretical Assumption being tested:	
Dependent Variable(s):	Strain
Control Variable(s):	
Hypothesis:	

MATERIAL PREPARATION

1.1. In accordance with our research goals, you will test several chicken skin specimens.
   a. You will conduct 3 replicates for the stress relaxation experiment, and one replicate each for the hysteresis and creep tests.
   b. To ensure adequate specimen samples are available for all experiments **you will prepare 8 samples**, only 5 of which will be used for final data analysis and 3 will act as backup specimens in the case of test failure.

1.48. You will use a scalpel to prepare your samples, your instructor will provide you a demonstration. Please include notes from your instructor demonstration for safe use of a hemostat to install and remove scalpel blades:

How to secure blade in hemostat	
How to install blade on handle	
How to remove blade from handle	

1.49. First begin by dissecting the skin away from the meat and bone

mm. It is probably easiest to use a *blunt dissection* technique for most of the skin removal. That is, you can use your gloved fingers to separate the skin from the muscle and bone.

nn. Use the scissors or scalpel only to cut through difficult connective tissue.

oo. Be careful not to cut or tear the skin while you are removing it from the leg so that you end up with the largest possible intact piece.

pp. Keep track of the orientation of the skin on the leg.

1.50. Cut the skin into 5 rectangles of approximately 20 mm by 65 mm in size using the specimen cutting stencil.

qq. When cutting the skin samples, try to choose locations of the skin that have consistent thickness. That is, each sample should have a consistent thickness throughout, but the thickness of individual samples may vary between each other.

1.51. Record the dimensions of your samples in Table 7-1. Keep track of which sample has which dimensions.

rr. You can label / keep track of your samples using an annotated paper towel under your petri dish.

ss. Measure the thickness of each skin sample with a micrometer in 3 different locations of the sample (record in Table 7-1). The average of the 3 measurements can be used to calculate cross-section.

tt. Measure only when you see the micrometer has touched the skin. Be careful not to be compress the sample (don't use the friction knob until the click), leading to an underestimate of the sample thickness and mechanical disruption of the tissue.

uu. Clean the micrometer with 70% ethanol after you are finished with it.

vv. Make sure the micrometer is turned off when you are finished with it, to save the battery.

1.52. Keep the skin moist by storing in PBS in a petri dish until it is ready to be tested.

1.53. Each sample will be sandwiched between small squares of scour pad in the testing machine clamps. Prepare 20 squares of scour pad approximately 20 mm x 20 mm in size.

Table 7-1 Specimen details for material thickness (mm), sample width (mm) and gauge length (mm). Specimen assignment for Stress Relaxation (SR), Hysteresis (H), Creep (C) tests or non-assignment (NA) for unused samples is also noted.

	Sample Thickness (mm)						
Replicate	Location 1	Location 2	Location 3	**Average**	Sample Width (mm)	Gauge Length (mm)	Assignment (SR/H/C/NA)
1							
2							
3							
4							
5							
6							
7							
8							
Average							
Standard Deviation							

STRESS RELAXATION TEST

1.54. Turn on the Nεwtσn TestResources control box (green button on the front). See Figure 6-3.

1.55. Open the TestResources software (Newton).

  ww. For the "Test Engineer" profile, Enter the password (Three-digit number labelled on the computer). See Figure 6-3.

1.56. Set up the Stress Relaxation test method using the software.

  xx. Click the Test Management tab and then select the "Stress Relaxation" test.

    i. This testing method will apply a large initial displacement at a very fast.

    ii. After the initial displacement is applied, the test method will then hold the sample at that location and measure load for a certain amount of time afterward.

  yy. The test method parameters are important to report in the methods section of an experimental report, follow the steps below to find and record the test parameters Table 7-2:

    iii. Under the Test Management Tab select your chosen test method "Stress Relaxation" and click on the edit (pencil) button.

    iv. Navigate to the Segments tab using the arrow buttons [→].

    v. Select Channel 1 and click on the edit (pencil) button. Select the Channels tab: record the test parameters in Table 7-2.

    vi. Select Channel 2 and click on the edit (pencil) button. Select the Channels tab: record the test parameters in Table 7-2.

Table 7-2 Stress Relaxation Test Parameters used in the Nεwtσn TestResources Software.

Segment	**Control Channel**	**Test Direction**	**Test Rate (mm/min)**	**Test Duration**
One				
Two				

1.57. Navigate to the Online tab to begin the test. Verify that the test frame is communicating with the computer by the green circle in the upper right-hand corner next to “Connection”.
   zz. Set up the test batches for each your samples. Refer to Module 6 page 6-5 to review instructions.
1.58. Load the first sample into the clamps with the scour pads between the clamps and the chicken skin to increase grip.
   aaa. Use the normal precautions to protect the load cell.
   bbb. Be careful not to jostle the clamp so much that you exceed the maximum on the load cell (224 N).
   ccc. Have one group member monitor the load cell on the software while another member loads the sample.
   ddd. Ensure that the sample is centered between the top and bottom clamps.
   eee. Adjust the fixtures using the slow jog buttons so that the sample is taut, but not exerting a load (or non-negligible load) on the load cell.
1.59. Once the sample is loaded into the top fixture, tare the load cell so that it is zeroed out.
1.60. Tare the position so that it is zeroed out.
1.61. With a digital caliper, measure your gauge length (the distance between your clamps), place these measurements in Table 7-1.
1.62. Edit your sample dimensions by double clicking on the dogbone icon next to the specimen label.
   fff. Make sure the specimen precision is increased to the appropriate number of significant figures. Make sure the units are correct (these should be mm not inches).
   ggg. Ensure that your batch id matches the sample replicate type you are testing.
1.63. Take a picture of the sample in the clamp and place it in Figure 7-2.
1.64. Click Tare and then click Play (▷) to start the test.
1.65. Take a picture of the sample once the test has ended and place it in Figure 7-2.
1.66. Repeat steps 1.58 to 1.65 with the other samples.
1.67. You will find your pdf reports and csv files in a folder on the desktop.
   hhh. Save these files to a USB for further analysis.

HYSTERESIS TEST

1.68. Set up the custom Hysteresis test method using the Newton software.
   iii. Click the Test Management tab and then select the “Hysteresis” test.
      vii. The first part of this test is like the test you performed in Module 6, except you will not load to failure, but return to the initial gauge length and repeat. From pilot experiments, we know that chicken skin starts to fail or have irreversible deformations around 30% strain.
      viii. Therefore, you need to setup a custom test protocol using a strain value that is no larger than 30% of your sample’s gauge length.
   jjj. Make a copy of the provided “Hysteresis” test.
      ix. Click on the duplicate button to make a copy of the Hysteresis protocol.

x. Type a new name for this protocol such as "Hysteresis_Sec1Gp2" and apply this new name by clicking the rename button.

kkk. The test method parameters are important to report in the methods section of an experimental report, follow the steps below to find and record the initial test parameters Table 7-2. Note we will change the applied strain "End Value" later in the procedure.

lll. Under the Test Management Tab select your custom test method with your chosen name and click on the edit (pencil) button.

xi. Navigate to the Segments tab using the arrow buttons [→].

xii. Select Channel 1 and click on the edit (pencil) button. Record the test parameters in Table 7-3.

Table 7-3 Hysteresis Test Parameters used in the Nεwtσn TestResources Software.

Segment	Control Channel	Test Direction	Test Rate (mm/min)	Pre-set End Value (mm)	Custom End Value (mm)*
One					

** The end value of the displacement-controlled ramp is what you need to ensure is less than 30 % of the gauge length*

1.69. Navigate to the Online tab to begin the test. Verify that the test frame is communicating with the computer by the green circle in the upper right-hand corner next to "Connection".

1.70. Batches are not required when you have only one sample.

1.71. Load the sample into the clamps with the scour pads between the clamps and the chicken skin to increase grip.

1.72. Tare the load cell so that the force and position is zeroed out.

1.73. With a digital caliper, measure your gauge length (the distance between your clamps), place these measurements in Table 7-1.

1.74. Edit your sample dimensions by double clicking on the dogbone icon next to the specimen label.

mmm. Make sure the specimen precision is increased to the appropriate number of significant figures. Make sure the units are correct (these should be mm not inches).

1.75. Go back to the test management tab, select your custom test method with your chosen name and click on the edit (pencil) button.

xiii. Navigate to the Segments tab using the arrow buttons [→].

xiv. Select Channel 1 and click on the edit (pencil) button. Edit the End Value to ensure it is less than 30% of the gauge length. Record this custom end value in Table 7-3.

1.76. Take a picture of the sample in the clamp and place it in Figure 7-2.

1.77. Click Tare and then click Play (▷) to start the test.

1.78. Take a picture of the sample once the test has ended.

1.79. You will find your pdf reports and csv files in a folder on the desktop.

nnn. Save these files to a USB for further analysis.

CREEP TEST

1.80. You will test your remaining skin sample using a simple creep test. A creep test is done by applying a constant load (stress) and measuring strain over time. You will perform this test on a custom wooden frame.

1.81. Load the chicken into the 3D printed clamps by sandwiching the clamps together and closing with a screw and wing nut.
1.82. The top clamp is attached to the frame with a rod and clevis pin.
1.83. Measure the initial gauge length (in units of mm) of the skin sample before you hang it, and right after you hang it, record these values in Table 7-4.
1.84. Attached the 500 g mass to the bottom clamp and immediately measure the gauge length, record these values in Table 7-4.
1.85. Make measurements of the skin sample length every two minutes for at least 20 minutes, record these values in Table 7-4.
1.86. Remove the weight, without removing the clamp, and let the sample rest. Take one last length measurement, record this value and the exact measurement time in Table 7-4.

Table 7-4 Creep Test gauge length measurements.

Data Point	Gauge length (mm)
Resting with clamps attached	
Hanging with clamps only	
Mass Added	
Hanging with clamps and mass: Time 0:00	
Time 2:00	
Time 4:00	
Time 6:00	
Time 8:00	
Time 10:00	
Time 12:00	
Time 14:00	
Time 16:00	
Time 18:00	
Time 20:00	
Mass Removed	
Hanging with clamps only: Time ≈ 21:00*	
	* Please note the exact time of the final sample here [_______]

CLEAN UP

1.87. Attendance points rely on the equipment being cleaned appropriately.
1.88. Collect all chicken waste in a Ziplock bag. The zip bag can be thrown in the regular trash.
1.89. Clean all electronic equipment (e.g., micrometers and calipers) with 70% ethanol.
1.90. Remove the blade as demonstrated, using a hemostat.
1.91. Safely dispose of scalpel blades directly into sharps container.
1.92. Wash everything else in the sink, in provided soapy water.
   c. This includes the clamps and clamp pins from the test frame and clamps from the creep test. Forceps, scissors, cutting boards, trays, etc.
1.93. Lay these out on an absorbent pad to dry.
1.94. Wipe down your work surface and the test frame with Anti-bacterial wipes.

	Pre Test Image	Post Test Images
Stress Relaxation Replicate 1:		
Stress Relaxation Replicate 2:		
Stress Relaxation Replicate 3:		
Hysteresis Replicate 1:		
Creep Replicate 1:		

Figure 7-2 Images of test samples before and after stress relaxation, hysteresis, and creep tests.

DATA ANALYSIS

1.95. You will find your pdf reports and csv files in a folder on the desktop.
  ooo. Save these files to a USB for further analysis.

Your instructor will provide step by step instructions for the MATLAB analysis required to process your Stress Relaxation, and Hysteresis experimental data. The steps below will provide an overview of this guidance.

Stress Relaxation Test

1.96. Using the import data function, load the Stress Relaxation replicate one .csv file, into MATLAB.
  d. Import the Stress, and Time data columns from the as a data Table.

1.97. Plot Stress Vs Time and identify the stress relaxation period as shown in Figure 7-3.

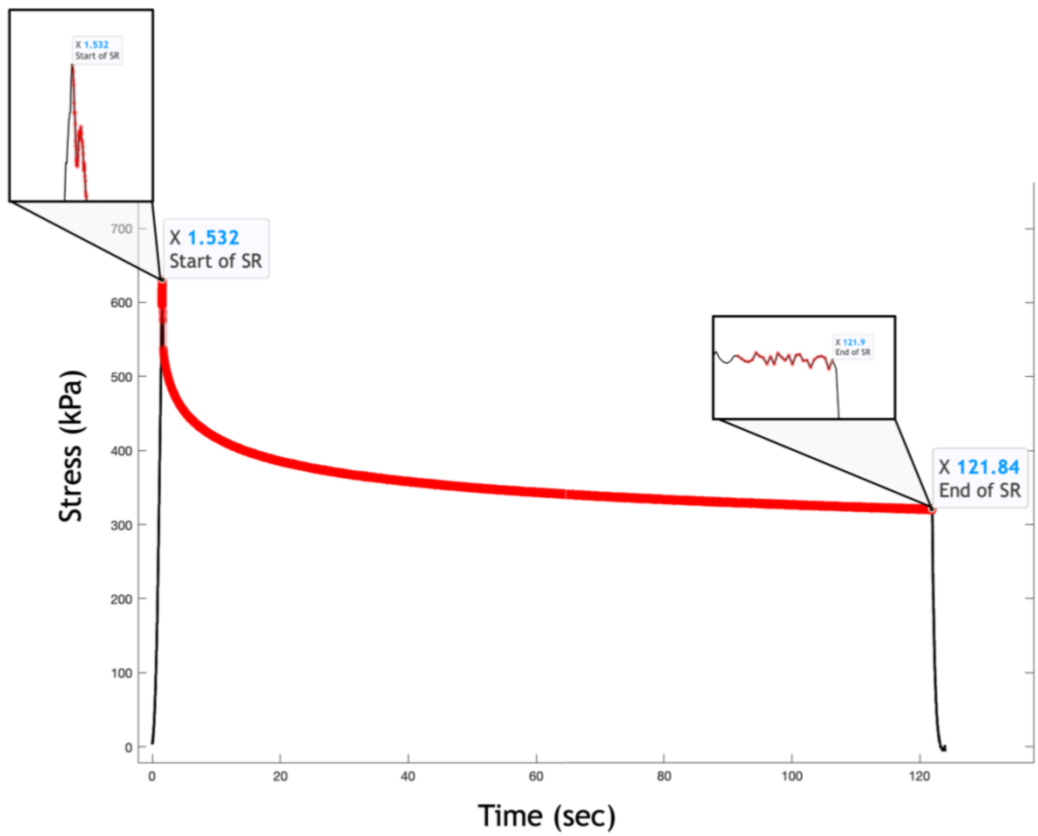


Figure 7-3 Stress (kPa) Vs Time (sec) plot with the Start and End of the Stress Relaxation (SR) period highlighted.

1.98. Using time data identified in stress vs time plot, trim table to exclude up-ramp and down-ramp data and only include the stress relaxation period.

1.99. Create new workspace variable for the stress and time data columns from the data table.
  e. Rename these workspace variables as “Time” and “Stress” to make further analysis more efficient.

1.100. Open the curve fitting tool from the apps tab. We will now fit the stress relaxation curve using first a 1st order equation (Equation 1) and then the second order equation (Equation 2).

Equation 1 $\sigma(t) = E_R\varepsilon_0(1 + (\frac{\tau_\sigma}{\tau_\varepsilon} - 1)e^{-t/\tau_\varepsilon})$

Equation 2 $\sigma(t) = E_R\varepsilon_0(1 + \left(\frac{\tau_{\sigma 1}}{\tau_{\varepsilon 1}} - 1\right)e^{-t/\tau_{\varepsilon 1}} + (\frac{\tau_{\sigma 2}}{\tau_{\varepsilon 2}} - 1)e^{-t/\tau_{\varepsilon 2}})$

1.101. For each equation:

f. Name your fit with the details of the test replicate and equation e.g., SR1Eqn1.
g. Load your time and stress data in for the X and Y data respectively.
h. Select "Custom Equation" from the equation drop down menu.
i. Type the following code in the custom code for each respective equation:

Equation 1: `Er*Eo*(1+((taus/taue-1)*exp(-Time/taue)))`

Equation 2: `Er*Eo*(1+((taus1/taue1-1)*exp(-Time /taue1))+(taus2/taue2-1)*exp(-Time/taue2))`

j. Make sure the highlighted code components (Time) match the x data variable name in the equation and in the function (f(Time)).
k. Record the results in

1.102. Clear your workspace and repeat steps 1.96 to 1.101 with stress relaxation replicates two and three.

Table 7-5 and

l. Table 7-6.
m. Export an image of each curve fit and place in Figure 7-4.
n. Save the Curve Fit Session to allow you to come back later to export figures or review data if needed.

1.103. Clear your workspace and repeat steps 1.96 to 1.101 with stress relaxation replicates two and three.

Table 7-5 Stress Relaxation Curve Fit Parameters from Equation 1.

Replicate	Eo (ε_0)	Er (E_R)	taue (τ_ε)	taus (τ_σ)	R^2
1					
2					
3					
Average					
Standard Deviation					

Table 7-6 Stress Relaxation Curve Fit Parameters from Equation 2.

Replicate	Eo (ε_0)	Er (E_R)	taue (τ_ε)		taus (τ_σ)		R^2
			taue1	taue2	taus1	taus2	
1							
2							
3							

Average							
Standard Deviation							

	Equation 1 Fit	Equation 2 Ft
Stress Relaxation Replicate 1:		
Stress Relaxation Replicate 2:		
Stress Relaxation Replicate 3:		

Figure 7-4 Images of curve fittings for both Equation 1 and Equation 2 for each stress relaxation replicate.

Hysteresis Test

1.104. Using the import data function, load the Hysteresis .csv file, into MATLAB.
   o. Import the Stress, Strain and Time data columns from the as column vectors.

1.105. Rename these workspace variables as “Time”, “Strain, and “Stress” to make further analysis more efficient.

1.106. Plot Strain V Stress to visualize the Hysteresis loops.

```
plot(Strain,Stress)
```

   p. Save this plot and place in Figure 7-4.

1.107. Plot Time V Strain to visualize the Hysteresis loops.

```
plot(Time,Stress)
```

   q. Save this plot and place in Figure 7-4.
   r. Run the “findpeaks” function.

```
findpeaks(Stress)
```

   s. As shown in Figure Use the Data Tips function to label and quantify the Y value of each stress peak.

t. Record these data in Table 7-7.

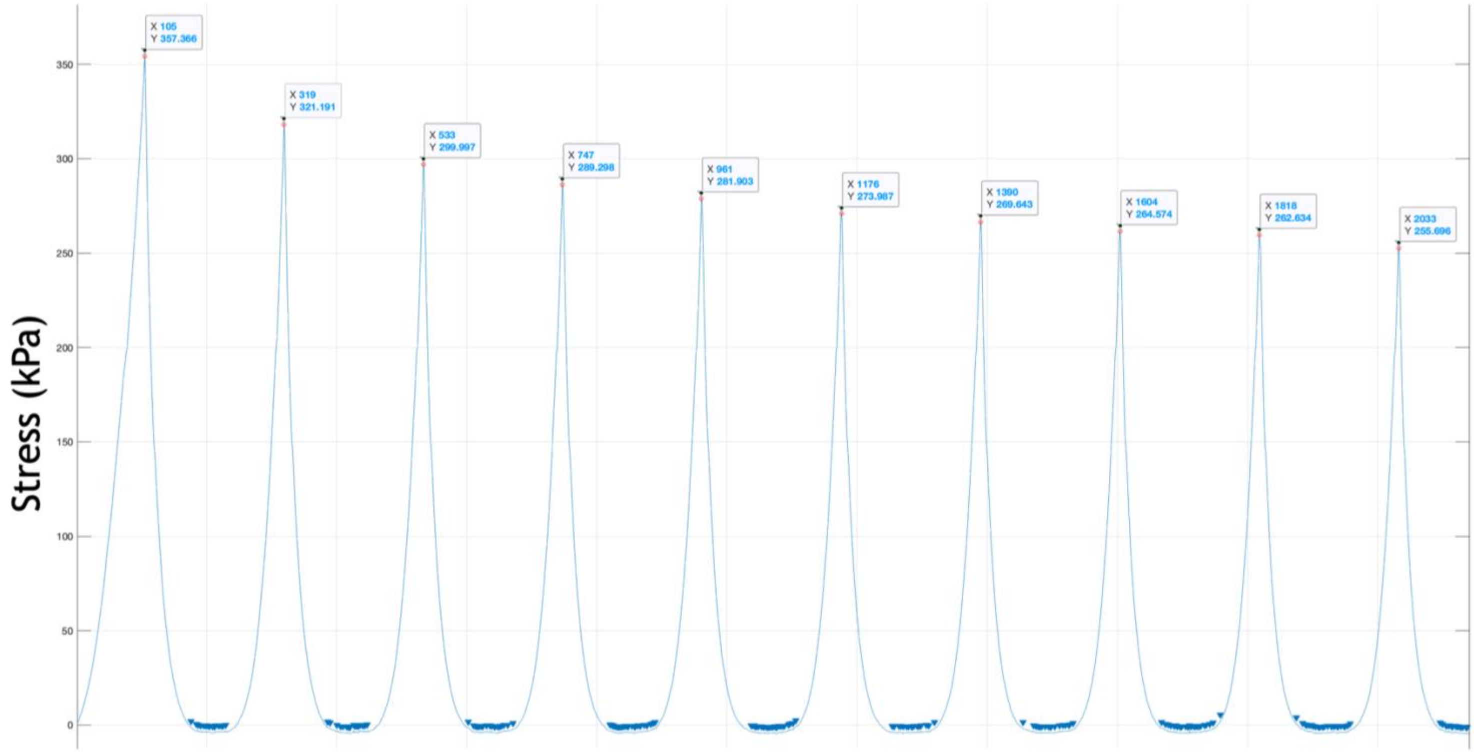


Figure 7-5 Stress (kPa) Vs Time (sec) plot with the peaks of each hysteresis cycle highlighted.

Table 7-7 Peak Stress (kPa) for each hysteresis loop and average and standard deviation of these values.

Cycle	Peak Stress(kPa)
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
Average	
Standard deviation	

1.108. Download and run the FigurePlotterHysteresis.m file Canvas, or from here, or by pasting the code below.

```
len = length(Strain);
x = Strain(1:(len/11));
y = Stress(1:(len/11));
```

```
figure(1);
tiledlayout(2,5);
for i = 1:11
    len = length(Stress);
    cycle = len/11;
    x = Strain(cycle*i:cycle*(i+1));
    y = Stress(cycle*i:cycle*(i+1));
    nexttile
    plot(x,y)
end
```

u. Save this plot and place in Figure 7-4.

Hysteresis Plot: Stress V Strain (a)	*Hysteresis Plot: Stress V Time (b)*
Hysteresis Multiplot Stress V Strain (c)	

Figure 7-6 Compilation of hysteresis plots. Stress (kPa) V Strain (a). Stress (kPa) V Time (sec) (b) and Stress (kPa) V Strain for each hysteresis cycle (1-10) (c).

Module 7 Post Lab Activity

Post-Lab Checklist:

☐ Document and submit completed procedure and post lab questions (Upload completed procedure page 7:1-7:16)

Post Lab Questions

You will complete an independent analysis of your data and answer the following post lab questions.

Stress Relaxation Analysis

Please review the data you acquired from the stress relaxation experiments, (Table 7-5 and Table 7-6), and detail with reference to your data which equation fits the data better.

What do the time constants in Table 7-5 and Table 7-6, tell us about the data.

Please review the data you acquired from the stress relaxation experiments, (Table 7-5 and Table 7-6), and detail with reference to your data if the data support your hypothesis.

Hysteresis Analysis

Create a Figure displaying the hysteresis cycle number Vs peak stress of each cycle from the data you acquired from the hysteresis experiment, (Table 7-7). Place this Figure along with an appropriate caption in the space below.

Figure	
Caption:	

Please qualitatively describe the relationship you observe in peak stress over cycle number as shown in the Figure above.

Please review the images in Figure 7-6 (c) and qualitatively describe the change in hysteresis loop area from cycle one through ten.

Please interpret the data you acquired from the hysteresis experiment, and detail with reference to your data if the data support your hypothesis.

Creep Analysis

Create a Figure displaying the time (sec) Vs strain from the data you acquired from the hysteresis experiment, (Table 7-4). Place this Figure along with an appropriate caption in the space below.

Figure	
Caption:	

Please interpret the data collected from the creep experiment, and detail with reference to your data if the data support your hypothesis.
