# How the Musculoskeletal System Works: Integrating Anatomy and Function

Biomechanics laboratory curriculum for Introductory Anatomy and Physiology courses with Vernier LabQuest and Dual-Range Force Sensor data collection interface.

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## I. Introduction

To produce and control movement and to support the body against gravity, the bones of the skeleton form a ***mechanical system*** with skeletal muscles, tendons and ligaments. The term system refers to parts, like these, working together to accomplish some task. The operation of the ***musculoskeletal system*** can be understood using the principles of ***lever systems***, simple mechanical devices that transmit ***force*** and produce ***torque***. Gaining a detailed knowledge of biomechanics is central to the practices of physical and occupational therapy, athletic training, and orthopedic medicine, as well as understanding the movement of one's own body. The background learned from this lab is a solid introduction. In this laboratory you will use a working arm model and your own body to investigate how movements of the human arm are accomplished by organized actions of the bones and muscles learned in previous anatomical studies.

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## II. Benchmarks

- Demonstrate the mechanical principles by which the musculoskeletal system works
- Define torque and learn how to calculate its value for a functioning lever system
- Identify and measure elements of a lever system in the arm model
- Learn how gravity acts on a lever system and identify the center of gravity in the arm model
- Learn to use simple algebraic operations for solving biomechanics problems
- Identify anatomical features and demonstrate selected actions of the arm in order to compare them with the arm model
- Learn to work in a collaborative group

## III. Prelaboratory Investigation

This section is designed to refamiliarize you with lever systems − something you have known about since you played on a teeter-totter as a child. The musculoskeletal system of our body operates as a series of lever systems, working on the same basic principles as a teeter-totter.

Each time you see directions in *italic print*, complete the activity before continuing.

### A. Mechanics of a Teeter-totter: a Problem

**__1**. *To begin the review, draw a diagram of the teeter-totter described in the following sentences. Use the space in* Fig 1.1. This teeter-totter has a board 4 meters long. At its mid-point, the board rotates on a support that is 45 cm above the ground. At each end of the board sits a child, one weighing 20 kg and the other 25 kg. The children have a problem because the smaller child stays up in the air sitting on her end of the board, while the larger child remains down on the ground.

**Fig 1.1.** The teeter-totter as a lever system

**__ 2.** *After you draw what is described, find two ways the children might solve their problem so that both can ride up and down on the teeter-totter. Modify the drawing in* Fig 1.2 *so the children balance.*

**Fig 1.2.** Balancing the teeter-totter lever system

### B. How Lever Systems Operate: Principles

**__1.** All lever systems have certain elements in common. *As each is described, identify it on* Fig 1.2 *and add the appropriate symbol.*

**__2.** A **lever** is a rigid structure that rotates around a **pivot (axis)**. *On* Fig 1.2 *draw a line through the lever and place a triangle at the pivot with one angle supporting the lever.*

**__3.** **Forces** that cause rotation usually are produced by the pull of muscles or the downward push of gravity on some object. Different forces acting on a lever system often oppose one another. Each force is applied at a specific place on the lever called the **point of force application**. *Draw an open circle (○) at the point where one force is applied and a closed circle (●) at the other point of force application.*

**__4.** A force can be represented by an **arrow** with its tail starting at the point of application and the head extending in the direction that the force pushes or pulls. *Place a bold arrow (➔) on the drawing to represent one of the forces (child's weight on the board) and a regular arrow (→) where the other force is applied. Show the directions of the forces by the orientation of the arrows.*

**__5.** One can measure the distance from the point of force application to the pivot. That distance is called the **lever arm (LA)** of the force. *Place brackets ({...}) showing the length of the lever arm for each of the two forces, and label them $LA_1$ and $LA_2$.*

**__6.** When sufficient force is applied to a lever arm, **rotational movement** occurs around the pivot. *To check the concept of rotational movement, bend and straighten your arm at the elbow.* Note that your forearm rotates in an arc, like the hands of a clock. *What are some other examples of rotational movement?*

**Examples: Rotational Movement**

______________________________

______________________________

______________________________

______________________________

__7. Rotational movement around a pivot (or joint) contrasts with **linear movement** in which an object moves in a straight line between two points. *To demonstrate linear movement place the tip of your index finger on the first letter of this line, then move it straight across the page to the last letter. What are some other examples of linear movement?*

**Examples: Linear Movement**

______________________________

______________________________

______________________________

______________________________

__8. *Observe the motion of various joints of your body. Is linear or rotational movement most common?* ____________________ *The linear movement of your finger across the page is produced by what kind of movement at joints of the hand and arm?* ________________ .

__9. Returning to the teeter-totter, notice that the weight (force) of each child tends to rotate its lever arm, pushing down toward the ground on his/her side. The children can balance each other on the teeter-totter when the tendencies to rotate clockwise and counterclockwise around the pivot are equal. To accomplish this with two children of different sizes, they can sit at different distances from the pivot. *Which child sits closer to the pivot?* ________________

__10. You can calculate exactly how far each child must sit from the pivot by understanding that the tendency of a force to cause rotation will change as its **point of application** (where the child sits) is shifted toward or away from the pivot. To determine this "tendency to rotate", called **torque (T)**, simply multiply the force (child's weight in kilograms, kg) times the length of the lever arm (in meters, m).

a. *If the 20-kg child sits exactly 2 meters (200cm) from the pivot, calculate the tendency of her weight to cause rotation (torque).*

**T =** ________

b. *Now use the following equation to determine how far the 25-kg child must sit from the pivot to produce the same torque in the opposite direction. Record the length of lever arm ($LA_2$).*

**$LA_2$ =** _______

**If the teeter-totter is balanced, $T_1 = T_2$**

Balancing the children

Torque 1 = Torque 2

$T_1 = F_1 \times LA_1 \quad T_2 = F_2 \times LA_2$

20 kg x 2m = 25 kg x ______

__11. The tendency of the force acting on a lever arm to produce rotation is called the **torque (T)** of that force. For example, in the prior step you calculated the torque created by the weights of the two children. *Based upon your work with the teeter-totter, state in words the relationship between the size of a force applied to a lever arm and the size of the torque it produces.*

***Force & torque***

Example:

the larger the force, the ____________ the torque

______________________________

______________________________

__12. *State the relationship between the length of the lever arm that the force acts upon and the size of the resulting torque.* Assume that the force remains the same.

***Length & torque***

______________________________

______________________________

______________________________

______________________________

__**13.** *Now state in your own words two ways torque can be increased.*

__**14.** It's important to use the correct units of measure in doing these calculations. For force you may use grams (gm) or kilograms (kg), as is convenient. For length you may use centi-meters (cm) or meters (m) as is convenient. For units of torque, combinations are used with a hyphen between (for example: gm-cm, kg-cm, or kg-m). *In the blanks below the equation, fill in examples of units, so those to the left correspond to those on the right side of the equation.*

**F**orce x **L**ever Arm length = **T**orque

F x L = T

(units) ___ ___ ___

__**15.** *Determine the torque produced by a 35-kg child sitting 1.5 meters from the pivot. Then determine the torque for a 15-kg child sitting 2.0 meters from the pivot. Do they balance?*

**Calculate the torques**

__**16.** Your instructor may provide you with a problem sheet to help you self-check your understanding of lever systems and torque.

## IV. Collaborative Learning

Collaborative learning is a strategy for improving students' efficiency and success on learning tasks that can be done in groups. It includes a division of labor on the task and specific roles for each student. Designed for tasks in which students are active learners (learning by doing, rather than by listening passively), collaborative learning encourages sharing and mutual help, rather than competition. Students must initially learn how to set up a group that works well, and how a task is organized to be done most effectively by a group. It is the purpose of this section to introduce collaborative learning methods which can then be used in the rest of this lab.

### A. General Guidelines:

- The work for each task is divided up among the members, and each person has a role to play that is important for the success of the group's work.
- All members must participate and contribute, but no one may dominate or take over the work. Each member's input should be respected.
- If one member has a task that is long, difficult or troublesome, other members should help out.
- All information gathered by the group is shared among the members. It is expected that all members will understand what has been done and studied.
- When the group does a new activity, the roles are rotated.

### B. Roles for Collaborative Learning

- **Reader/Coordinator (RC)** keeps your group on task by carefully reading the instructions and then checking them off as each task is accomplished.
- **Instrument operator(s)(IO)** gathers all equipment and materials for the group, organizes the setup, and is primary operator of the equipment (with the help of others as needed). He/she organizes the clean up.
- **Timer-Researcher (TR)** gathers infor-mation, including help from the lab instructor, and times lab procedures.
- **Recorder-reporter (RR)** records data, notes, and answers to questions as the group proceeds through the lab; this person also reports to the class when groups share their results.

### C. Group Organization

Set up your own group, assigning roles with volunteers. Rotate the assignments next time. *Complete Table 1.1.*

Table 1.1. Roles for collaborative learning.

| Task/Assignment | Group Member |
|---|---|
| Reader/Coordinator | |
| Instrument Operator | |
| Timer-Researcher | |
| Recorder-Reporter | |

## V. Exploration

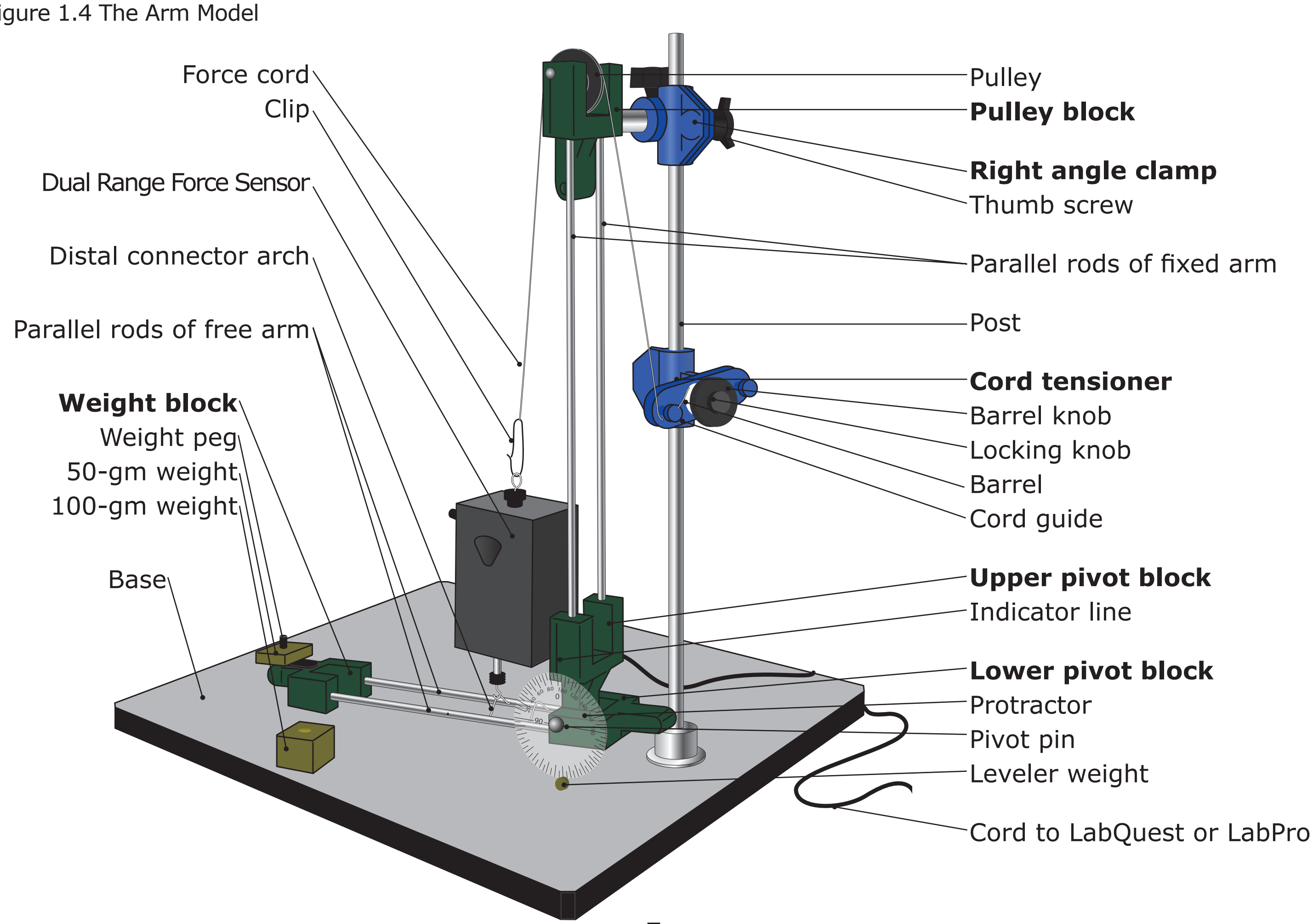
Start working collaboratively here.

**Problem:** A teeter-totter was arranged so that the board is 2 meters long on one side and 3 meters long on the other. A 20-kg child sits at the end of the 3m side and exactly balances another child sitting at the end of the 2m board. How big is the child on the 2m side?

Fig. 1.3. Exploration diagram and calculations. *(Your work)*

*Diagram the arrangement in Fig 1.3, do the calculations and be ready to explain your answer.*

Figure 1.4 The Arm Model



# VI. Investigations of Biomechanics: The Arm Model

## A. Introduction

__1. *Briefly examine and compare your own arm with the arm model. Note a few similarities and differences.*

__2. The arm model is a FUNCTIONAL, not an ANATOMICAL, model. *What do you think would be the distinctions between these two kinds of models? How might each be used in learning about the human body?*

***Functional vs. Anatomical Models***

__3. Functional models are not intended to accurately replicate the appearance of body parts. Rather, they are simpler devices that work, in some ways, like the actual structure. *View the arm model without operating it. Predict some ways it might work like your arm.*

***Prediction: How the functional model works like your arm***

__4. This model will enable you to simulate specific arm movements and easily measure the forces and distances that help you master basic muscle mechanics.

## B. Operation of the Arm Model

__ 1. The instrument operator in your group should operate the model with assistance, as needed, from other group members. The arm model (Fig 1.4) simulates the actions of **flexion** and **extension** at the human elbow joint.

__2. The name of each part is underlined the first time it is mentioned. *Find it in Figure 1.4 and highlight the label.*

__3. *To become familiar with the operation of the model, place a 50-gm weight on the weight peg located near the distal end of the free arm as it rests on the base. The peg should be rotated to a position furthest from the pivot pin joining parts at the elbow.*

Figure 1.5 The Vernier LabQuest™


__4. *Turn on the LabQuest™, and touch the "Graph mode" icon with the stylus. With the free arm resting on the base and no tension on the arm from the force sensor, press the "Collect" button (right arrow button). Be careful not to bump the model or the table.* As it measures during the default duration of 10 seconds it will record and display a graph of the force. (It should be reading close to 0.00 N in the small box on the upper right of the screen, when the Dual-Range Force Sensor is not lifting any weight. If it is not, notify your instructor. The LabQuest™ should also be reading in Newtons (N). If it is reading in lb. use the "Sensor" menu at the top of the screen to change the units to N. (One N equals 9.8 Kg.)

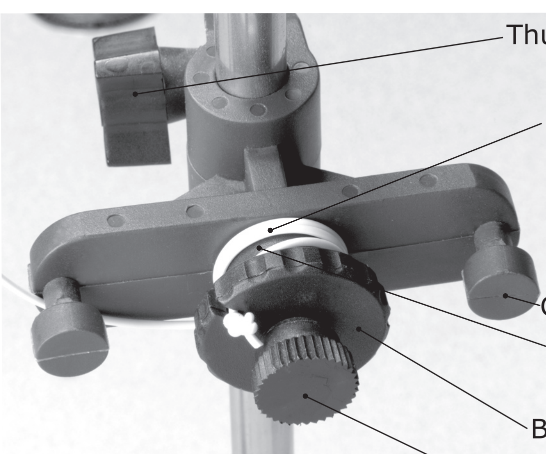
__ **5.** Save the recorded data on the LabQuest by activating the "file cabinet" icon on the upper right of the screen above the Force reading. The "Run" indicator on the upper right of the screen will increment to "Run 2", your next data collection period. Do this each time you finish a new measurement so you have a saved record of each step of your experiment. Either now or later you can highlight a section of the recording by dragging the stylus over the data you wish to use, and then, using the "Analyze" menu, calculate the force "Statistics" which compute an average value, the "mean", that will display in a window on the right. Averaging is the most accurate way to determine the true force value, since the sensor always has some "noise" in its output and doesn't produce a perfectly constant reading.

__**6.** *Identify the following parts on the cord tensioner.* The green force cord is wound around the black barrel. The barrel knob is directly connected to the barrel and has a wavy edge. The smaller knurled locking knob is closest to the operator as he/she faces the back of the model.

***Note:*** Newer versions of the arm model have been outfitted with a cord tensioner that is shown in Fig. 1.6 below. If you have an older model with a metal handle and red cap screws, refer to the addendum at the end of this module for directions on its use.

__**7.** *Use two hands to operate the cord tensioner as explained here. To raise the free arm from its resting position on the base, hold the larger barrel knob in position with one hand while you loosen (counterclockwise) the locking knob with the other hand. Now twist the barrel knob clockwise until you raise the free arm to the desired angle. Tighten the lock knob securely.*

Figure 1.6 Cord Tensioner




__**8.** The angle is determined using the plastic protractor located at the pivot. *To get an exact right angle, align the 180° (horizontal) mark with the white indicator line on the lower pivot block. Making small adjustments can be accomplished by loosening the locking knob, twisting the barrel knob, and tightening the locking knob again. It is helpful if one student views the angle on the compass as the instrument operator works the cord tensioner.*

__**9.** *When your alignment is achieved, touch the "file cabinet" icon on the LabQuest screen to start a new recording without losing your first one. It will display "Run 2". (Do this each time you make a new measurement so you have a saved record of your entire experiment.) Press the "Collect" button on the LabQuest again to measure the force. When the reading is completed, determine the value as before and record the measurement in Table 1.2. Convert your readings in N to gm by dividing N by 0.0098 N/g. Remember that* ***1 N = 9.8 Kg****.*

Table 1.2. Force measurements supporting the arm model and 50 gm weight.

| Measurement | Value (N) | Value (gm) |
|---|---|---|
| 1 | | |
| 2 | | |
| 3 | | |

__**10.** *Two other group members should repeat the procedure to take force readings.* (The steps are summarized in the Fast-Trac diagram to save you time and reading.) *Record results in Table 1.2. Were there any differences from the first reading? If so, repeat the operation to obtain consistent readings.*

__**11.** The Fast-Trac Procedure summary is provided to help you efficiently use the model without reading the longer directions over and over again. Refer to it frequently until you are confident in doing the operations.

**Fast-Trac Procedure Summary***

Free arm rests on the base.

↓

Confirm zero reading on force sensor

↓

Loosen the locking knob

↓

Twist the barrel knob until the arm is at the desired angle

↓

Tighten the locking knob

↓

Check the angle with the protractor and make adjustments as needed

↓

Record the force and enter it in Table 1.2

↓

Hold the barrel knob in one hand

↓

Loosen the locking knob with other hand

↓

Control the descent of the free arm to the base with the barrel knob

↓

Tighten the locking knob

* If you have an older arm model outfitted with a force cord handle and catchpin assembly (red cap screws), use directions in the addendum at the end of this laboratory module instead of directions #7-10 and this Fast-Trac summary.

## C. The Arm Model as a Lever System

__ **1.** Elements of a lever system identified earlier in the teeter-totter are arranged differently in the arm model, but all the same ones can be found. *Follow the steps below to locate them and sketch them on* Fig 1.7 on page 9. *Try to locate the same elements on your own arm. For this exercise, take the weight off the model.*

__**2.** The **pivot** is the structure around which the free arm rotates on the fixed arm. *Draw a triangle at the pivot in Fig 1.7 with one angle supporting the free arm.*

__**3.** The **effort force ($F_e$)** tends to flex the elbow. *Locate its point of application on the free arm and draw an arrow (→) with its tail at the point of force application and its head in the direction the force is pulling.*

__**4.** Use the Fast-Trac procedure to measure the $F_e$ required to support the arm without a weight at 90º. *Record your results in Table 1.3 under the effort row, "Force (N)" column.*

__**5.** The **effort (lever) arm (EA)** is the distance between the point where the effort force is applied and the pivot. *Bracket ({...}) the length of the effort arm and label it EA. Now measure its length using a centimeter ruler. Enter the value in the effort row, "arm length" column of Table 1.3. In completing the data tables in these labs, enter values only in the blank cells.*

__**6.** The **resistance force ($F_r$)** tends to extend the elbow. It comes from the downward action of gravity on the free arm and so corresponds to the weight of the free arm. The weight of the free arm should be indicated on a sticker near the pivot. *Enter it into the resistance row, "Force (gm)" column of Table 1.3.*

__**7.** The resistance force should be represented with an arrow having a double tail ( => ). To position the arrow correctly, you need to locate the center of gravity for the free arm. The **center of gravity (CoG)** is the imaginary point along the free arm around which all its mass is evenly distributed. It is marked on one parallel rod of your model. *Draw the resistance force arrow down from the center of gravity in Fig 1.7.*

Table 1.3. Opposing torques in flexion of the arm model.

| | Force (N) | Force (gm) | Arm Length (cm) | Torque (gm-cm) |
|---|---|---|---|---|
| Observed Effort | | | | |
| Resistance | NA | | | |

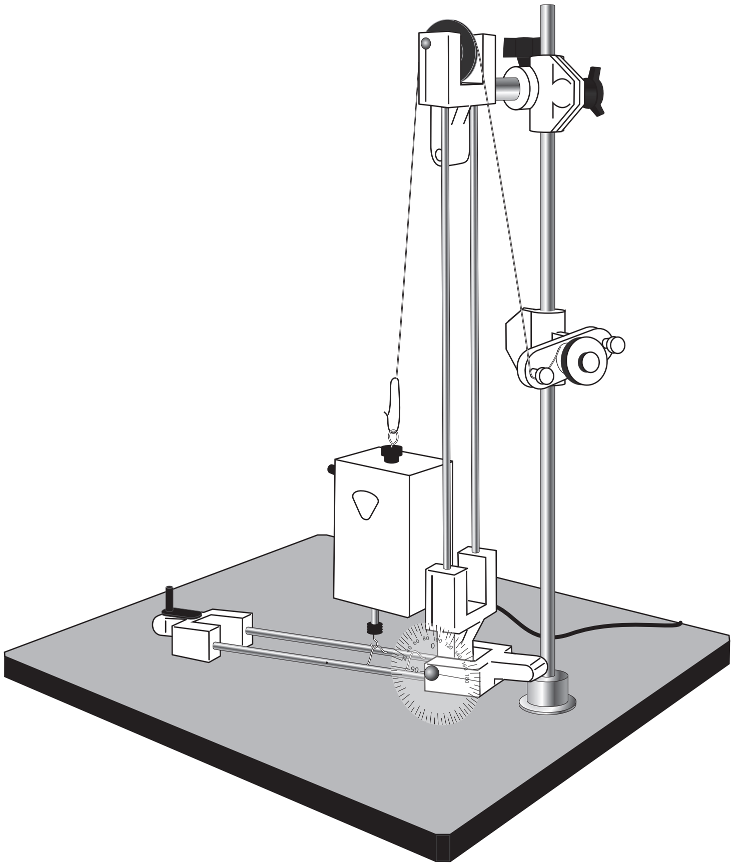


Figure 1.7. Compare the arm model and human arm.

**__8.** *Measure the distance between the center of gravity (CoG) and the pivot, and record it in Table 1.3 under resistance "arm length."* This is the **resistance arm length (RA)**.

**__9.** *To understand center of gravity, take a pencil or other long narrow object and try to balance it successfully on the edge of your index finger. Avoid sudden movements that could flip the pencil into someone's face.* By trial and error you will find a point of balance, and if you make a short line from there to the exact center of the pencil shaft, you would reach the imaginary point which is its center of gravity. Around this point, the mass of the pencil is evenly distributed. When you support the pencil with the edge of a finger, the entire weight of the pencil is concentrated directly beneath the center of gravity, at the point of contact with your finger. *If you are unsure about this concept, discuss it with members of your group or your instructor.*

**__10.** You could do this same balancing exercise with the free arm of the model, if it were not attached. After locating the center of gravity for the free arm, we treat it as the point where all of its weight is concentrated in making our torque calculations.

## D. Calculations: Opposing Torques in the Action of the Arm Model

**__1.** When the free arm is raised and supported at 90°, two opposing torques are being generated. The first, called the ______ __________, tends to raise and support the free arm. The second, called the _________ _____________, results from the action of gravity and tends to rotate the free arm downward. When the arm is stationary or in equilibrium, the two torques are equal. In this situation, are the opposing forces equal? Check Table 1.3. Explain in the box below.

***How can the opposing torques be equal when the opposing forces are unequal?***

**__2.** *Using the data you gathered in Table 1.3, calculate the $T_r$ and $T_e$ record them in the torque columns.*

***Calculate $T_r$ and $T_e$***

**__3.** *Compare the two torques you calculated to determine the difference between them. If you divide that difference by $T_e$ and multiply by 100, you obtain the percent error. Do it now.* ***% error*** ________ . *What factors might have contributed to the error?*

***Possible sources of error?***

## E. How much force is required to lift a 100-gm weight?

__**1.** *Locate the 100-gm weight that comes with the model. Imagine unhooking the Force Sensor from the arm and suspending the 100-gm weight by a string directly to it. What would the measured force be?* _____ (Not a trick question!)

__**2.** *Check your prediction and the record the reading on the LabQuest. _________ . Reattach Force Sensor to the distal connector arch on the free arm.*

__**3.** *Place the 100-gm weight on the weight peg of the free arm. Check that the weight peg is in its distal position.* ***Do not raise the arm now.*** *Based upon work in the previous experiment, your goal is to predict how much effort force ($F_e$) will be required to lift the 100-gm weight and the free arm of the model. Use the following information.*

- Here the torque of the resistance $T_r$ has two components: first, the torque produced by the weight of the free arm itself; second, the torque produced by the weight. The lever arm for the free arm itself extends from the pivot to the _______________ for the free arm. The lever arm for the weight extends from the weight peg to the ________.
- Measure the lever arm for the weight and calculate the torque it produces.
- Locate the torque produced by the free arm itself from Table 1.3.
- Add the two torques together to get the total resistance torque $T_r$.
- Now using the torque equation, determine how much effort force ($F_e$) is needed to suspend the arm off the base at 90°. Show your calculations and explain your reasoning.

***Predict $F_e$ to raise the 100-gm weight***

______________________________________________

______________________________________________

__**4.** *Now test your prediction using the Fast-Trac procedure to determine the effort force that is required. Explain any differences between observed and predicted torque values.*

______________________________________________

______________________________________________

__**5.** *As time permits you can experiment further by swinging the weight peg 180° and making the measurement again with the arm model. Predict the new effort force ($F_e$) required and then make the measurement. Explain the difference in $T_e$ required compared to the value obtained in Step 4*

__**6.** *Save all your data on the LabQuest using the "File" menu.* When you tap the "Name" box on the "Save" screen a keyboard will appear. It's a good idea to use a file name that identifies your lab group, the date and the experiment such as, "biomech_grp2_04_04_2008".

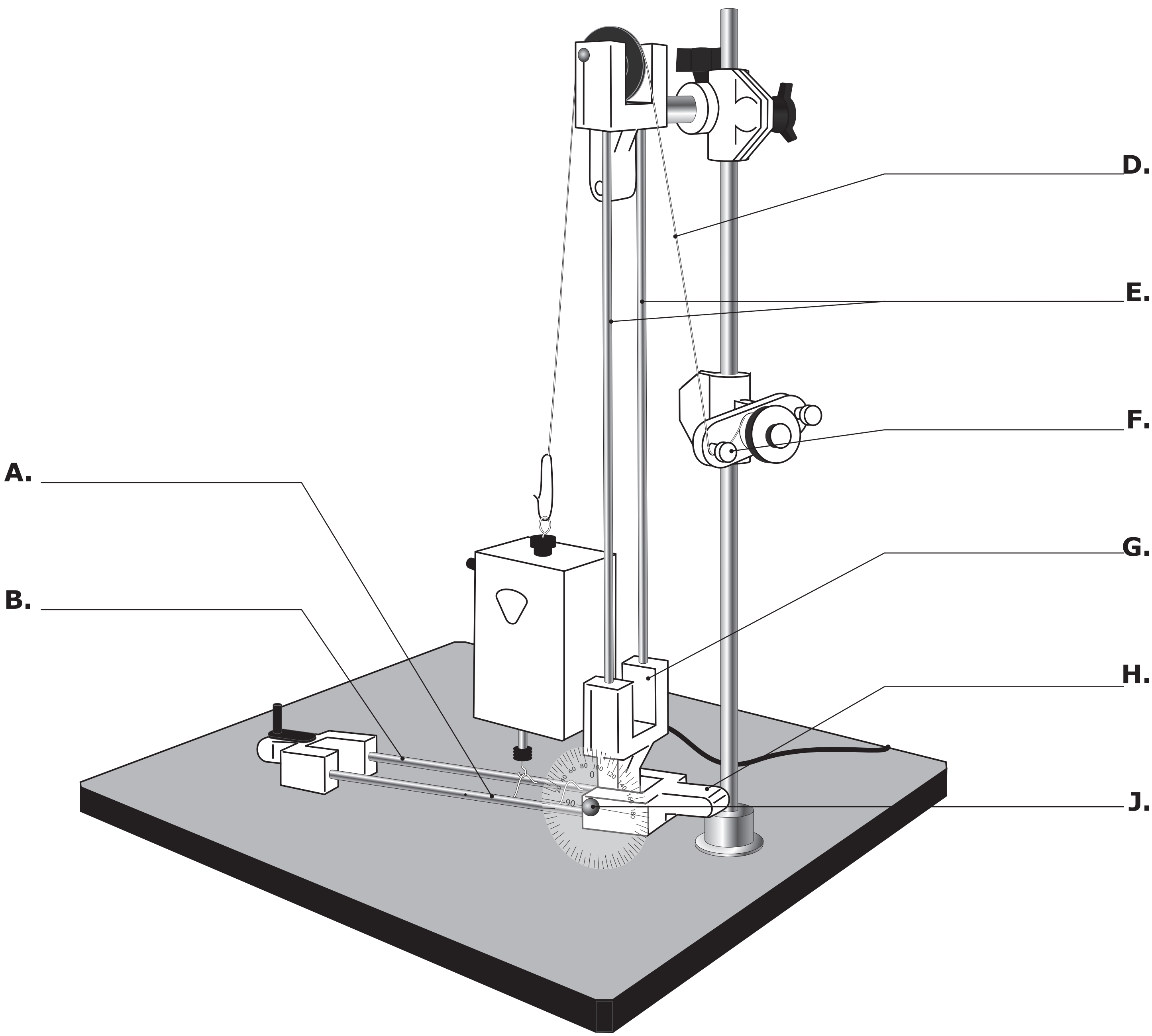
__**7.** *How might the length of a person's arm change the effort force ($F_e$) required to lift a weight?*

F. How does the arm model compare to the human arm?

__**1.** *Based on your experience with the arm model, which actions of the elbow can the arm model mimic? ___________________ .*

__**2.** In Fig. 1.8 various structural components of the arm model are labeled with letters. *Determine the corresponding anatomical elements of the human arm that are represented. Place your answers directly on the illustration.*

Figure 1.8 Compare the arm model and human arm



## VII. Functional Anatomy: The Arm

### A. Introduction

Understanding biomechanics is the first of two steps in learning about musculoskeletal function. The second requires a review of functional anatomy that includes analysis of movement using your own arm. In this section be sure to observe carefully and perform the actions yourself as much as possible.

### B. Structures and Actions

__**1.** *Identify the bones that comprise the elbow joint. List them here.*

***Bones of the Elbow Joint***

________________________________

________________________________

________________________________

__**2.** *Next, standing in the anatomical position, bend your arm at the elbow so that the angle between the upper arm and forearm decreases. This action is called __________. Now, demonstrate the opposite action and notice what happens to the angle at the elbow. This action is called ____________________.* Movements like these that are opposing are called antagonistic movements.

__**3.** *Next consider the elbow carefully and determine which of the three bones you mentioned earlier are moving during the actions of flexion and extension. List them here.*

________________________________

________________________________

__**4.** *Using your text, lab manual, or a "muscleman" model, try to identify the three muscles of the anterior compartment (upper arm) responsible for flexion of the arm at the elbow.* These muscles get shorter and thicker as they contract. The largest and most superficial muscle is called the __________ ____________. Beneath it is the smaller ___________________. The smallest of the three lies laterally with most of its mass located distal to the elbow. It is the ____________________________ muscle.

__**5.** Each of these elbow flexors attaches to and moves a single bone. For each muscle, indicate the bone that serves as the distal attachment. Try to be as precise as you can by also indicating the specific portion of the bone that serves as the attachment point.

| Flexor | Distal attachment |
|---|---|
| 1 | |
| 2 | |
| 3 | |

__**6.** A second pair of movements that is possible at some joints is adduction/abduction. **Adduction** is movement across a joint that brings a structure or limb closer to the midline. **Abduction** is the antagonistic movement and therefore results in the structure moving ___________________ the midline. *Demonstrate these actions at your shoulder joint. Now, place your arm at your side in the anatomical position. Lock your shoulder in place so no movement can occur at that joint. Try adducting and abducting the elbow joint? Describe what happens.*

________________________________

________________________________

__**7.** To identify anatomical structures that limit movements at the elbow, we need to review the soft tissues. Joints are held together and stabilized, typically by the design of the participating **bones, ligaments** that connect bone to bone, and sometimes **tendons**. In the case of the elbow, it is the first two, bones and ligaments, which primarily maintain joint integrity.

__**8.** Ligaments are composed of connective tissue rich in collagen and elastic protein. They have very high tensile strength as well as considerable resiliency. These attributes allow ligaments to hold bones tightly together while at the same time enabling them to stretch and recoil as the bones of the joint are moved. *Move to a study skeleton and determine what bony structures limit adduction and abduction at the elbow. Identify them here.*

________________________________

________________________________

__**9.** *If there is an elbow model available in your lab, examine it. If not, refer to your text, lab book, or any available reference. Identify those ligaments that prevent adduction and abduction at the elbow and list them here.*

________________________________

________________________________

__**10.** Now that you have identified each, briefly explain how the **ulnar** and **radial collateral** ligaments stabilize the elbow joint.

***How ligaments stabilize the elbow***

______________________________________________

______________________________________________

______________________________________________

__**11.** *Now, to analyze flexion at the elbow, place your arm in the anatomical position. Flex it very slowly, and observe any changes in the shape and length of muscles above the elbow. To make these changes more dramatic, hold a heavy object (a textbook or a weight) in your hand as you perform the action. As you flex, have a member of the group grasp and observe the muscles on the anterior of your upper arm and describe the changes.*

***Muscle changes with flexion***

______________________________________________

______________________________________________

______________________________________________

__**12.** *Next analyze extension at the elbow starting with your arm at your side flexed to 90º, as you hold a weight. Allow your arm to slowly straighten, and have your partner determine the activity in the triceps and biceps brachii by palpating. Which muscle(s) should be contracting? ________________ During this slow elbow extension, which is/are producing force?________________ During this activity, does the biceps brachii shorten or lengthen? ____________ . What about the triceps?______________________ .*

__**13.** Previously you determined that the biceps contracts in causing flexion at the elbow joint. Now, you should have discovered that it is also active during extension. *How can this be true? Try to explain it.*

***How does the biceps act in both flexion and extension?***

______________________________________________

______________________________________________

______________________________________________

__**14.** You have seen that the biceps brachii flexes the arm at the elbow against resistance by shortening. This type of muscle contraction (where the muscle shortens as it contracts) is called **concentric contraction**.

__**15.** You have also seen that starting with the arm bent at a right angle, the *action of gravity* on the forearm and on the object you were holding can cause the arm to straighten. In this case, the biceps can slow or brake extension at the elbow by *contracting and lengthening* at the same time. This type of muscle contraction is called **eccentric contraction.**

__**16.** A third type, **isometric contraction**, occurs when the muscle is contracting to produce force but is staying the same length. *Can you identify a situation in which isometric contraction of the biceps has occurred in the exercises you just completed?*

______________________________________________

__**17.** *To analyze elbow extension in another situation, grip a textbook or a weight in your hand and raise your arm straight up over your head as if you were asking a question in class. Keeping the upper arm raised, flex the elbow slowly to 90º. Your partner should note the activity of the triceps and biceps.*

______________________________________________

*Does the triceps shorten or lengthen during this action (circle one)?*

__**18.** *From the 90° position, slowly extend (straighten) your elbow. As you complete this activity, have your partner grasp your triceps muscle and note any changes in tension.________________________________
Also note if the triceps shortens or lengthens during the extension.*

______________________________________________

______________________________________________

__**19.** *Repeat steps 17 and 18 with the goal of determining what type of contraction is occurring in each phase? Identify all three types of contraction in this sequence and describe where they occur:*

a. concentric __________________
b. eccentric ___________________
c. isometric ___________________

__**20.** The force of muscle contraction can cause flexion and extension at the elbow. What is the second type of force that can cause the same movements? *Give an example.*

______________________________________________

______________________________________________

______________________________________________

## VIII. Problems

*(Do the problems assigned by your teacher after the lab.)*

1. Determine the torque produced by a 22-kg child sitting 1.5 meters from the pivot. For a 10-kg child sitting 2.0 meters from the pivot.

2. Using the teeter-totter from Fig 1.2, solve the following. A 15-kg child came to play with the 10-kg child on the teeter-totter. The smaller child sat all the way at one end of the teeter-totter. Where must the 15-kg child sit to exactly balance her new playmate? Use the equations and correct units in showing your solution.

3. How is the lever system of the arm model different from that of the teeter-totter? How is it the same?

4. The point of force application and the center of gravity are important locations in determining torques in the operation of the lever systems. Define or explain each. How are they related? How are they different?

5. A physical therapist is rehabilitating a patient's arm by having him flex and extend the arm. She uses a weighted belt that can be attached anywhere on the arm.
   a. Where should the therapist put the belt at the beginning of therapy to provide the gentlest effect? Explain
   b. How should the belt be moved as the patient gets stronger? Explain.

6. Give two examples, using your own body, of how rotational movements at joints can produce linear movements. Don't use the example presented in the laboratory.

7. On the elbow joint of your own arm, locate the following elements of a lever system as it causes the action of flexing: pivot, effort arm, effort force, resistance arm, resistance force, points of force application.

8. A large arm model was constructed with a free arm which weighs 1 kg and has a center of gravity 12 cm from the pivot.
   a. If the force cord is attached 1 cm from the pivot, what force must be applied to support the free arm at 90°?
   b. An additional weight of 1 kg is supported by the arm at a distance of 20 cm from the pivot. What is the total torque of the resistance? What effort force will be required to support the arm and weight?

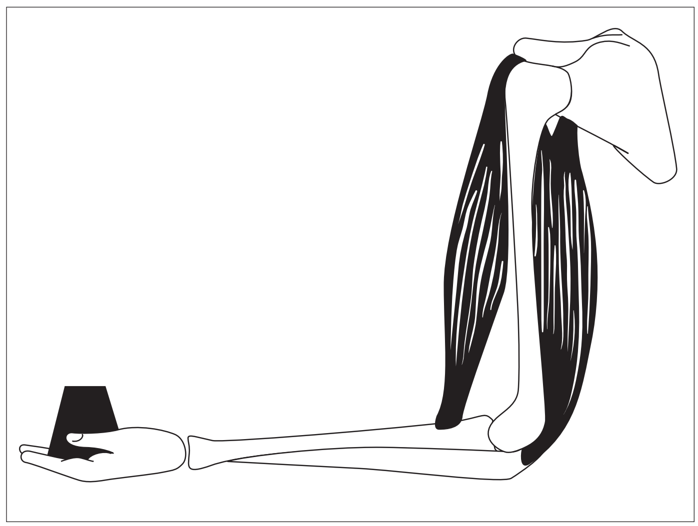
9. In housing for older or weakened people, doorknobs with long handles are used instead of standard round ones. Can you explain, in terms of decreased force requirements what the advantage of the long handles is? Use the concept of torque in your explanation.

10. Two children played on the teeter-totter.
    a. On one side sat a 10-kg child, 1.8 m from the pivot. What is the total torque tending to rotate the teeter board downward on that side.
    b. On the other side of the teeter-totter sat a 12 kg child 1.8 m from the pivot. What is the total torque tending to rotate this side downward?
    c. The father of the children applies force to the teeter board on the side of the smaller child. He applies it 2.0 m from the pivot. How much torque will he have to produce to balance the larger child? How much force will he need to apply?

11. a. When you are flexing the arm, compare the sizes of the $T_e$ and $T_r$.
    b. Do the same comparison when you are slowly extending your arm.
    c. How do the values compare when you hold the arm flexed at 90°?

12. What is experimental error? Give an example from this lab investigation. List a series of factors (5 or more) that might contribute to experimental error in this study.

Fig. 1.9. Human Arm



13. Fig 1.9 shows a simplified diagram of the human arm. On this diagram draw the symbols representing elements of a lever system for flexing the elbow. Label them indicating both the part of the arm and the part of the lever system. For example, you would place the labels "elbow" and "pivot" indicating that structure.

# IX. Key Terms and Concepts

force
musculoskeletal
lever system
pivot (axis)
lever arm
effort force ($F_e$)
resistance force ($F_r$)
effort arm (EA)
resistance arm (RA)
torque (T)
center of gravity (CoG)
torque of the effort ($T_e$)
torque of the resistance ($T_r$)
point of force application
biomechanics
total torque of the resistance
linear movement
rotational movement
experimental error
torque equation
collaborative learning
flexion
extension
biceps brachii
brachioradialis
mechanical system