

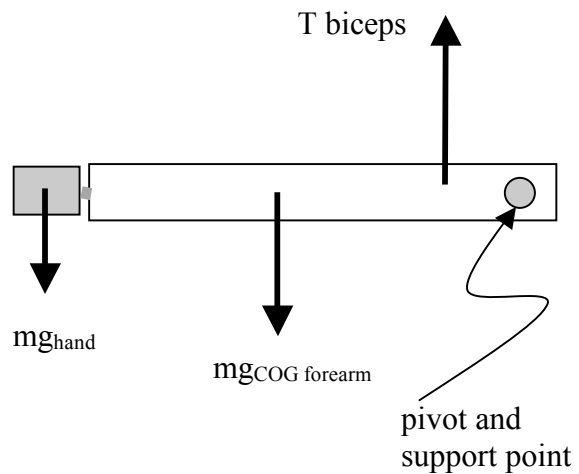
Introduction

In this lab you will use a model of the lower arm to investigate the force that the bicep muscle needs to exert for you to be able to lift and hold your lower arm and hand at various angles, and for you to be able to support masses in your hand when the lower arm is horizontal. You should review sections 8.1 to 8.4 of your text before coming to the lab. You will need to use the concepts of center of gravity, torque, and rotational equilibrium.

The figure shows a diagram of an arm bent at about 90°. The upper arm is vertical and there is a mass supported by the hand. We will assume that the bicep muscle pulls vertically upwards on the upper bone (the *radius*) of the lower arm. For this experiment we will work with conditions in which the tricep muscle is relaxed and not exerting a force. The lower arm rotates about a pivot point close to the base of the *humerus* (the bone in the upper arm).

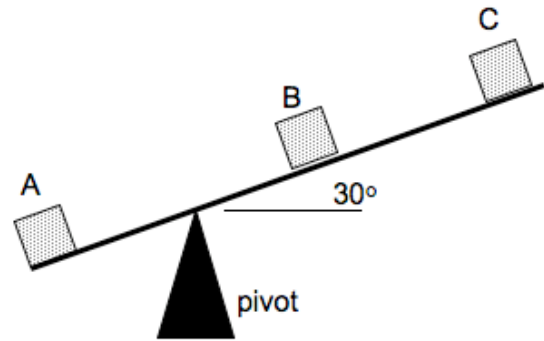


Our model of this system is simple but contains all the important features. The lower arm and hand are represented by a length of wood supported at the elbow end by a rod passing through a hole. The force of the rod on the wood is the same as the force of the *humerus* on the *ulna* and *radius*. A mass can be attached to the end of the wood at the hand end. The bicep is represented by a string pulling upwards with the tension measured by the force sensor. The mass of the wood itself represents the mass of the lower arm and hand. The protractor and plumb line allow measurement of the angle of the “forearm”.

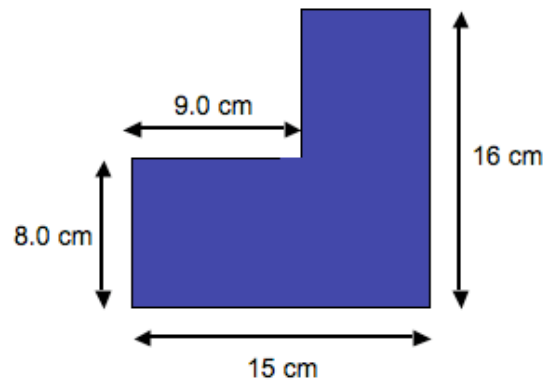


Pre-lab Questions

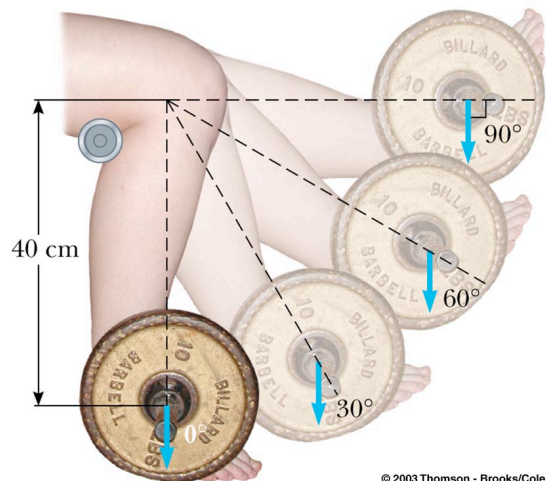
1. On the seesaw shown to the right, mass A is 20 kg, mass B is 10 kg, and mass C is 5.0 kg. Mass A is 0.50 m from the pivot. Mass C is 1.2 m from the pivot. The seesaw is at an angle of 30 degrees from the horizontal. Calculate the torques of mass A and mass C about the pivot. Where you should place mass B in relation to the pivot for the system to be in rotational equilibrium (*i.e.* there is no net torque on the system)?



2. Calculate the center of mass of the object to the right. Assume the mass is uniformly distributed.



3. As part of a physical therapy program following a knee operation, a 4.5 kg object is attached to an ankle and leg lifts are done as sketched in the figure. Calculate the torque about the knee due to this weight for the four positions shown.



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4. Write "I checked my grades online". (Please, actually check them on webct.ucsd.edu. And if you have some problems then it would be better to solve them with your TAs during the last lab instead of emailing them during finals week.)

Group Activity:

- You will find a metal L bracket on your lab bench. Measure its dimensions and calculate the position of its center of mass (CoM).
- Devise a practical method to measure the position of the CoM. Your TA will help you. Use this method to find the CoM experimentally. Measure and note your results.
- Compare your experimental result with your calculation. Do they agree? Should they agree?

Experiment A

Examine the model of the human forearm. Record the masses and lengths for your apparatus. This section of the experiment will measure the force of the bicep muscle as a function of the mass supported by the hand when the forearm is horizontal. **Make sure the “bicep” string is vertical.**

- A1.** Start with no extra mass in the hand and set the force sensor to the 50N scale. With reference to the pivot point, calculate and record the torque of the weight of the forearm, and the torque of the tension of the bicep muscle. With reference to your diagram of the setup, which torques are clockwise and which are counter clockwise? Do the CW and CCW torques balance?
- A2.** Repeat the measurement of bicep tension when the hand supports 0.2 kg, 0.4 kg and 0.6 kg masses. Make a table showing your data and the calculated torques. Do the torques continue to balance?
- A3.** What are the sources of uncertainty in your calculation of the torque? What are the values of these uncertainties?

Experiment B

In this part of the lab, you will investigate if you need a greater bicep tension when your lower arm is horizontal, or when it is at an angle (always keeping the upper arm vertical). Before you start this part of the lab pick up a 1 kg mass in your hand and try the experiment on your own arm. Compare the lower arm horizontal with it at 45° above and below the horizontal. Record your best (subjective) evaluation of the relative bicep forces at these angles.

For the experiment, use a 0.2 kg mass in the “hand” throughout.

- B1.** Repeat A2 above (lower arm horizontal) with the 0.2 kg mass and confirm your results are consistent.
- B2.** Now set the arm to 30° below the horizontal and repeat. Measure, calculate, and compare your clockwise and counter-clockwise torques. Do they balance?
- B3.** Repeat B2 at 45° below horizontal, 30° above the horizontal, and 45° above horizontal. In each case, check CW and CCW torques.

- B4.** From your data in B1, B2, and B3, how does the bicep force change as a function of angle? From your data, assess how confident you can be with your result.
- B5.** Find a general expression for the tension in the bicep muscle in terms of the mass and relative positions of the forearm and hand. How does the tension depend on the angle above or below the horizontal? Calculate the tension you would predict at each angle you used in parts B2 and B3.
- B6.** Do your predictions from B5 agree with your measurements?