Chapter 3: Problems

Due: **Thursday, February 13th**

Learning Objectives: Upon completion of the following problems you should be able to:

1. Draw a free body diagram showing the forces acting on the body segments described in the problem.
2. Solve for moment arms associated with forces given the appropriate body segment dimensions and orientations.
3. Use static equilibrium and torques to solve for unknown muscle forces.
4. Use static equilibrium and force to solve for joint reaction forces.

Problems to Complete

Before attempting to solve the problems create a guide to help you with the steps of these problems. Within your guide, at a minimum, include the following information:

- Identify the known and unknown quantities in the problem. Are there any quantities that are not known but could be known with one or two extra calculations?
- Draw a free body diagram for the problem.
- Identify which equations you could use to solve the problem.
- Set up equations and work them down as far as possible before plugging in any numbers.

Problem 1

A PT is rehabbing the knee of a patient recovering from ACL reconstruction surgery in which the surgeon used the middle third of the patella tendon as a graft. Therefore, there is a concern about high levels of force on the patella tendon. The PT has the patient extend her knee against the resistive force of gravity. The patient is sitting upright with her hips in 90° of flexion. The leg is in static equilibrium. You are asked to determine the force going through the patellar tendon. Here is what you know about the patient:

- Mass of the lower leg (m) = 3 kg
- Distance from knee joint center to center of mass of the lower leg (L) = 30 cm
- Moment arm of the patellar tendon (T) = 2 cm
- Knee flexion angle = 30°

A) Determine the force going through the patellar tendon in this scenario.

Problem 2

An individual is doing a lateral shoulder raise exercise, abducting the weight from their side up until their arm is horizontal. You are concerned that, due to the magnitude and orientation of the joint reaction force, this exercise has the potential to pinch the rotator cuff, and over time, lead to rotator cuff injury. To analyze this you decide to calculate the joint reaction force during this exercise. You know the following information about the participant:

- The arm is straight and held at so that it is abducted up 60° from vertical.
- The mass of the arm is 5 kg (consider the humerus and forearm as a single segment for this problem).
- The distance from the shoulder center of rotation to the COM of the arm is 35 cm.
- The subject is performing the exercise with a 7 kg weight (~15 lbs).
- The full length of their arm (distance from shoulder center of rotation to weight) is 70 cm.
- The moment arm of the deltoid muscle (primary agonist for this movement) is 2 cm.
- In this position, the angle between the tendon for the deltoid muscle and the humerus is 10° at the insertion site on the bone.

A. Draw an appropriate free body diagram for this problem.

B. Solve for the force being exerted by the deltoid muscle in this situation.

C. Solve for the joint reaction force between the head of the humerus and the glenoid cavity given the information above. Make sure to provide both the magnitude and direction.

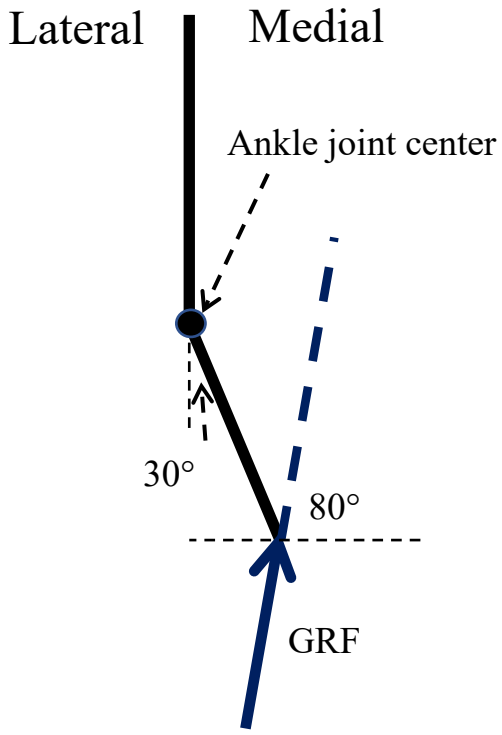
D. Your answer to part C does not account for any co-contraction or actions of other muscles. However, rarely is only one muscle active. What would happen to the joint reaction force you calculated in part C if the latissimus dorsi muscle were to produce a force equal to the force of the deltoid muscle you calculated in part B? (consider the insertion point and line of action for the latissimus dorsi muscle).

Problem 3

Lateral ankle sprains are a common lower extremity injury in sports, with close to 1 million injuries occurring annually. One way to screen an athlete for likelihood of ankle injury is to assess their "time to stabilization". An athlete hops from a set distance landing on 1 foot on a force plate and the clinician evaluates the time it takes the athlete to become "stable" (i.e. the force vector stabilizes around bodyweight and the athlete maintains balance). Athletes who show longer stabilization times are more likely to sustain a lateral ankle sprain than athletes who can stabilize quickly.

Unfortunately, during your testing, one of your athletes actually sprains their ankle. Here is what you know about the person at the time the injury occurs:

- They sprained the **LEFT** ankle, landing with their tibia vertical and their calcaneus inverted 30° as shown in the images below.
- The peak ground reaction force measured during this landing was 1500 N, pointing superior-medially, oriented at an angle of 80° above horizontal.
- The distance from the ankle joint center of rotation to the point where the ground reaction force is applied to the foot is 10 cm.
- Based on the joint configuration at landing, there are two anatomical structures which can resist this inversion of the foot:
    - The peroneus longus muscle:
        - This muscle attaches to the foot halfway between the ankle joint center and the point of ground reaction force application under the foot.
        - At the time of injury, the muscle is generating maximal force. Peak force generated by this muscle is 1800 N.
        - The orientation of the peroneus longus muscle relative to the foot is 20° and the force vector points superior-laterally.
    - The calcaneofibular ligament:
        - In this joint configuration, the ligament has a moment arm relative to the ankle joint center of rotation of 1 cm.
        - The force vector for this ligament points superior laterally at an angle of 50° above horizontal.



A) Draw a free body diagram for this scenario. Above left shows an illustration of this injury. Above right is a posterior view of the start of a free body diagram. This should get you started but needs more information added to be complete. The above is **NOT** big enough, so please redraw yours ***using an entire sheet of paper*** for the diagram. At a minimum, make sure your free body diagram shows the following:
    a. The ground reaction force and appropriate moment arm (1 point)
    b. The force from the peroneus longus muscle and the appropriate moment arm (1 point)
    c. The force from the calcaneofibular ligament and appropriate moment arm (1 point)
    d. The joint reaction force acting at the ankle (1 point).

B) Solve for the moment arm of the ground reaction force relative to the ankle joint center and the moment arm of the peroneus longus relative to the ankle joint center (2 points, 1 point each).

C) You now know the force from the ground reaction force and its moment arm, the force from the peroneus longus and its moment arm, and the moment arm for the calcaneofibular ligament (given initially in the problem). Based on this information, and assuming the person is in static equilibrium at this point, solve for the force in the calcaneofibular ligament (5 points).

D) Cadaveric testing suggests the calcaneofibular ligament is likely to sustain damage when forces greater than 5,000 N are applied. Based on your results from part 3, is there likely to be damage to the calcaneofibular ligament in this situation? Justify your answer. (2 points).

E) To solve for the joint reaction force at the ankle you need to decompose all the forces into x and y pieces. Calculate the following:
    a. The x and y components for the calcaneofibular ligament force (1 point).
    b. The x and y components for the peroneus longus force (1 point).
    c. The x and y components for the ground reaction force (1 point).

F) Using the information from part 5, solve for the **resultant** joint reaction force acting at the ankle joint (5 points). Report the magnitude and orientation of this force.

G) One of the major complications with lateral ankle sprains is when a bone bruise occurs at the same time. Typically in order to have a bone bruise occur, the joint reaction force needs to be incredibly high. In fact, cadaveric testing has suggested it needs to be over 16 times body weight. If the person in this problem has a body weight of 850 N, then based on your answer to part 6, are they likely to sustain a bone bruise in this situation? Justify your answer (2 points).