Tendon

Triceps muscle (extensor)

Biceps muscle (flexor)

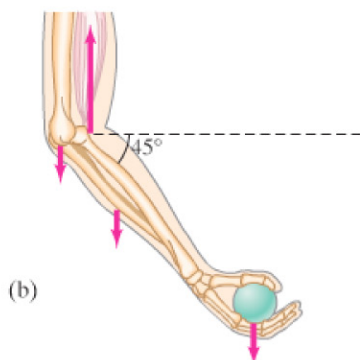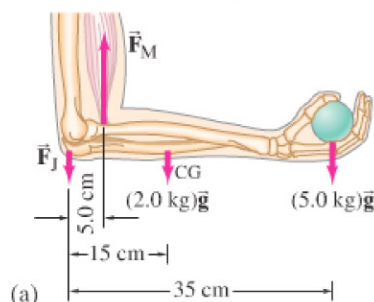Insertion

FIGURE 9–12 The biceps (flexor) and triceps (extensor) muscles in the human arm.

👤 **PHYSICS APPLIED**
Forces in muscles and joints

FIGURE 9–13 Example 9–8.

$\vec{F}_M$

$\vec{F}_J$

5.0 cm

CG

$(2.0\,\text{kg})\vec{g}$

$(5.0\,\text{kg})\vec{g}$

—15 cm—

(a)

—35 cm—

45°

(b)

👤 **PHYSICS APPLIED**
Muscle insertion and lever arm

👤 **PHYSICS APPLIED**
Forces on the spine, and back pain

*9–3 Applications to Muscles and Joints

The techniques we have been discussing for calculating forces on objects in equilibrium can readily be applied to the human (or animal) body, and can be of great use in studying the forces on muscles, bones, and joints for organisms in motion or at rest. Generally a muscle is attached, via tendons, to two different bones, as in Fig. 9–12. The points of attachment are called *insertions*. Two bones are flexibly connected at a *joint*, such as those at the elbow, knee, and hip. A muscle exerts a pull when its fibers contract under stimulation by a nerve, but a muscle cannot exert a push. Muscles that tend to bring two limbs closer together, such as the biceps muscle in the upper arm (Fig. 9–12) are called *flexors*; those that act to extend a limb outward, such as the triceps muscle in Fig. 9–12, are called *extensors*. You use the flexor muscle in the upper arm when lifting an object in your hand; you use the extensor muscle when throwing a ball.

EXAMPLE 9–8 **Force exerted by biceps muscle.** How much force must the biceps muscle exert when a 5.0-kg mass is held in the hand (*a*) with the arm horizontal as in Fig. 9–13a, and (*b*) when the arm is at a 45° angle as in Fig. 9–13b? Assume that the mass of forearm and hand together is 2.0 kg and their CG is as shown.

APPROACH The forces acting on the forearm are shown in Fig. 9–13 and include the weights of the arm and ball, the upward force $\vec{F}_M$ exerted by the muscle, and a force $\vec{F}_J$ exerted at the joint by the bone in the upper arm (all assumed to act vertically). We wish to find the magnitude of $\vec{F}_M$, which is done most easily by using the torque equation and by choosing our axis through the joint so that $\vec{F}_J$ contributes zero torque.

SOLUTION (*a*) We calculate torques about the point where $\vec{F}_J$ acts in Fig. 9–13a. The $\Sigma\tau = 0$ equation gives

$$(0.050\,\text{m})F_M - (0.15\,\text{m})(2.0\,\text{kg})g - (0.35\,\text{m})(5.0\,\text{kg})g = 0.$$

We solve for F_M:

$$F_M = \frac{(0.15\,\text{m})(2.0\,\text{kg})g + (0.35\,\text{m})(5.0\,\text{kg})g}{0.050\,\text{m}} = (41\,\text{kg})g = 400\,\text{N}.$$

(*b*) The lever arm, as calculated about the joint, is reduced by the factor $\sin 45°$ for all three forces. Our torque equation will look like the one just above, except that each term will have its lever arm reduced by the same factor, which will cancel out. The same result is obtained, $F_M = 400\,\text{N}$.

NOTE The force required of the muscle (400 N) is quite large compared to the weight of the object lifted (49 N). Indeed, the muscles and joints of the body are generally subjected to quite large forces.

The point of insertion of a muscle varies from person to person. A slight increase in the distance of the joint to the point of insertion of the biceps muscle from 5.0 cm to 5.5 cm can be a considerable advantage for lifting and throwing. Champion athletes are often found to have muscle insertions farther from the joint than the average person, and if this applies to one muscle, it usually applies to all.

As another example of the large forces acting within the human body, we consider the muscles used to support the trunk when a person bends forward (Fig. 9–14a). The lowest vertebra on the spinal column (fifth lumbar vertebra) acts as a fulcrum for this bending position. The "erector spinae" muscles in the back that support the trunk act at an effective angle of about 12° to the axis of the spine. Figure 9–14b is a simplified schematic drawing showing the forces on the upper body. We assume the trunk makes an angle of 30° with the horizontal.