pounds (ft-lb), or inch-pounds (in-lb). When torque is produced, the force arm is referred to as a moment arm, but as mentioned, clinicians commonly interchange the two terms.

An increase in the moment arm length increases the torque produced by a force ($T = F \times L$). For example, if you apply manual resistance at a patient's thigh as she performs a straight-leg raise, your torque is less (or you have to produce more force for the same resistance against the patient) than if you positioned your hand at the patient's ankle. With your hand at the ankle, your effort is less for the same torque production because your moment arm is longer (from the patient's hip to ankle vs. hip to thigh). Conversely, if a weak patient has a difficult time performing a straight-leg raise against gravity, bending the knee to shorten the leg's resistance-arm length may permit the patient to lift the leg without assistance.

Torque can also be altered by changing the force. Placing a 4.5 kg weight on an ankle produces twice as much torque as a 2.25 kg weight during a knee extension exercise. A muscle's torque changes as a joint moves through its range of motion. This occurs, in part, because the muscle's line of pull and the angle of pull change causing the muscle's moment-arm length to change.

VIDEO Go to the online video and watch **video 3.1**, which demonstrates short levers versus long levers.

Line of Pull

The **line of pull** of a muscle is the long axis of the muscle. The **angle of pull** is the angle between the long axis of the bone (lever arm) and the line of pull of the muscle. The angle of pull and moment arm of the muscle both change as the joint goes through its range of motion. As demonstrated in figure 3.12, the maximal amount of torque is produced when the angle of pull of the muscle is 90° and the moment arm is at its greatest length. In this position all the muscle's force is directed to produce only rotation. As the muscle's angle of pull increases or decreases from 90°, the part of the force that contributes to rotational motion (rotational force) decreases, and the part that does not contribute to rotation (nonrotational force) increases, so the ability to produce rotational motion—or torque—diminishes. How much of a muscle's force is used as rotational force (vector) and how much is used as nonrotational force (vector) depend on the angle of pull and the moment arm length at that angle. The muscle's nonrotational force will tend to either stabilize the joint by providing compression, or it will destabilize the joint by providing a distraction force, depending on the angle of pull. The farther the angle of pull is from 90°, the more of the muscle's force stabilizes or destabilizes the joint and the less of the muscle's force rotates the joint. For example, the biceps, seen in figure 3.13, has a nonrotational force component that is pulling the ulna into the elbow and provides stability to the joint. It also has a rotational force component moving the forearm through its arc of

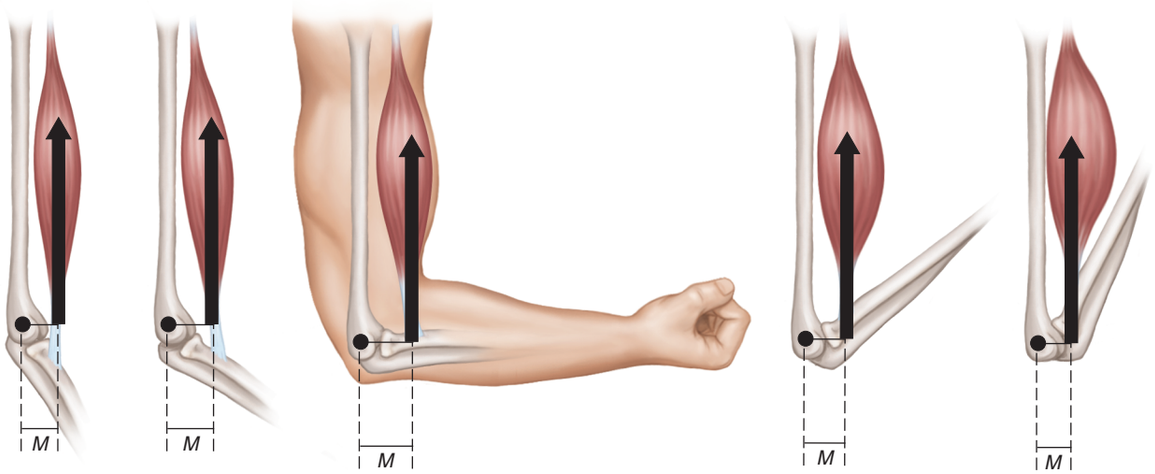

Figure 3.12 The angle of pull changes as range of motion changes. The most rotary force occurs when the muscle's angle of pull is 90°. On either side of 90°, the muscle's force is only partly used to produce joint motion; the other part tends to either compress or distract the joint. M = muscle's moment arm.

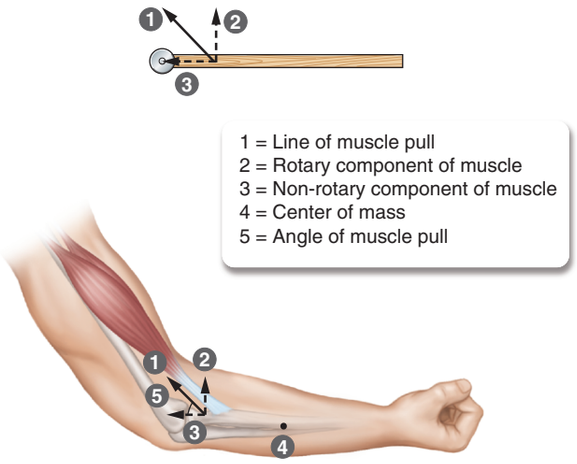

Figure 3.13 Rotary and nonrotary components of a force application: *(a)* mechanical representation, *(b)* muscle representation. With one end of a stick anchored, a force applied will rotate the stick around the fixed end. In *(a)*, the closer to vertical the force application to the stick is, the greater the amount of force applied only to rotation will be. The remaining force is applied as a compressive force toward the anchored end.

motion. In therapeutic exercise, the mechanics of each joint and the angle of pull of the muscles surrounding the joint should be appreciated. A recently dislocated shoulder, for example, should not be placed in positions that encourage surrounding muscle activity to destabilize it. For this reason, early rehabilitation of this condition warrants avoiding overhead or full lateral-rotation positions where the nonrotational forces that distract the joint are significant.

CLINICAL TIPS

The ability of a force to cause a rotational movement, or torque, is affected by the angle at which the force acts on a body part. Since joint motion (rotation) is the desired activity, a muscle is most efficient when all of its force is dedicated to creating joint motion. When the muscle does not produce all its force for joint motion, some of its force is directed at either compressing or distracting the joint. Forces compressing the joint make it more stable, while forces distracting it make it less stable. However, there are occasions such as with arthritis when compressing a joint may be painful and therefore undesirable. Clinicians must be aware of forces created by muscles so they can modify the movement to meet patient needs.

Angle of Pull

Angle of pull of a muscle is an important concept in therapeutic exercise. If you want to produce the maximal torque from a muscle, the joint must be positioned so that the muscle being worked has a 90° angle of pull on the extremity.

This concept also works for external forces applied to the body. With pulleys, the maximal resistance occurs when the angle of pull of the pulley's rope is 90° to the extremity being resisted, as shown in figure 3.14. With free weights, the maximal resistance occurs when the pull of the weight is perpendicular to the ground regardless of the extremity's position; in this position the line of pull of the weight (relative to the earth) is 90°. For example, when a supine patient performs elbow flexion with a weight, the greatest resistance is at the start of the motion when the patient's elbow moves from full extension to flexion, as seen in figure 3.15. If the patient is standing or sitting, however, the maximal resistance from the weight is when the elbow is at 90°. The clinician must realize how changes in position alter resistance arm lengths. The clinician should always know when in the range of motion maximum resistance occurs.

Physiological Muscle Advantages

What we have been discussing thus far is the mechanical advantage of muscles, which relates to the angle of pull and moment arm of muscles and the amount of resistance a muscle must overcome to produce motion. **Physiological advantage** is a muscle's ability to shorten. This is an important functional concept in therapeutic exercise. A muscle has the most physiological advantage when it is at its full resting length. The full resting length of a muscle is the extent to which

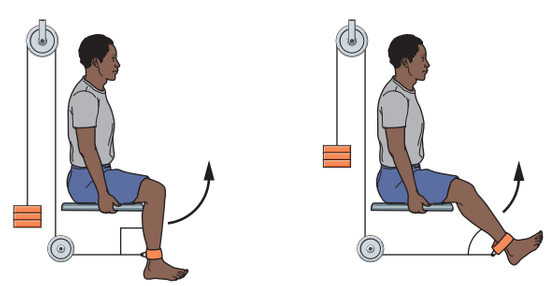

Figure 3.14 With this pulley arrangement, the greatest resistance is produced at 90° of knee flexion.