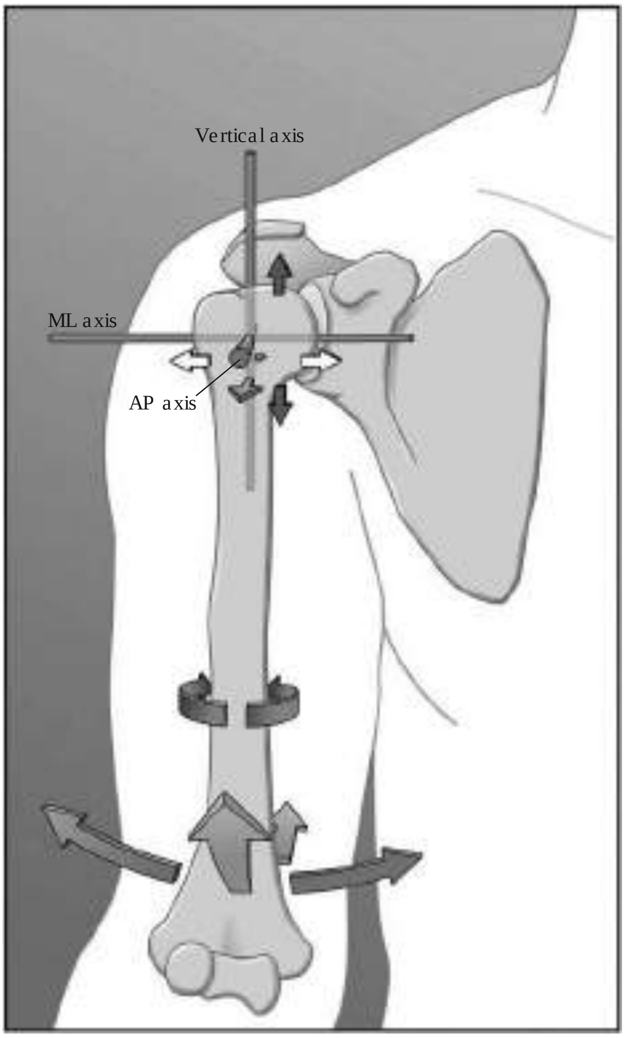


FIG. 1.5 The right glenohumeral (shoulder) joint highlights three orthogonal axes of rotation and associated planes of angular motion: flexion and extension *(green curved arrows)* occur around a medial-lateral *(ML)* axis of rotation; abduction and adduction *(purple curved arrows)* occur around an anterior-posterior *(AP)* axis of rotation; and internal rotation and external rotation *(blue curved arrows)* occur around a vertical axis of rotation. Each axis of rotation is color-coded with its associated plane of movement. The short, straight arrows shown parallel to each axis represent the slight translation potential of the humerus relative to the scapula. This illustration shows both angular and translational degrees of freedom. (See text for further description.)

Unless specified differently throughout this text, the term *degrees of freedom* indicates the number of permitted *planes of angular motion* at a joint. From a strict engineering perspective, however, degrees of freedom apply to translational (linear) as well as angular movements. All synovial joints in the body possess at least some translation, driven actively by muscle or passively because of the natural laxity within the structure of the joint. The slight passive translations that occur in most joints are referred to as *accessory movements* (or joint "play") and are commonly defined in three linear directions. From the anatomic position, the spatial orientation and direction of accessory movements can be described relative to the three axes of rotation. In the relaxed glenohumeral joint, for example, the humerus can be passively translated slightly: anterior-posteriorly, medial-laterally, and superior-inferiorly (see short, straight arrows near proximal humerus in Fig. 1.5). At many joints, the amount of translation is used clinically to test the health of the joint. Excessive translation of a bone relative to the joint may indicate ligamentous injury or abnormal laxity. In contrast, a significant reduction in translation (accessory movements) may indicate pathologic stiffness within the surrounding periarticular connective tissues. Abnormal translation within a joint typically affects the quality of the active movements, potentially causing increased intra-articular stress and microtrauma.

OSTEOKINEMATICS: A MATTER OF PERSPECTIVE

In general, the articulation of two or more bony or limb segments constitutes a joint. Movement at a joint can therefore be considered from two perspectives: (1) the proximal segment can rotate against the relatively fixed distal segment, and (2) the distal segment can rotate against the relatively fixed proximal segment. (In reality, both perspectives can and often do occur simultaneously; although for ease of discussion and analysis, this situation is often omitted within this text.) The two kinematic perspectives are shown for knee flexion in Fig. 1.6. A term such as *knee flexion*, for example, describes only the *relative motion* between the thigh and leg. It does not describe which of the two segments is actually rotating. Often, to be clear, it is necessary to state the bone that is considered the rotating segment. As in Fig. 1.6, for example, the terms *tibial-on-femoral movement* and *femoral-on-tibial movement* adequately describe the osteokinematics.

Most routine movements performed by the upper extremities involve distal-on-proximal segment kinematics. This reflects the need to bring objects held by the hand either toward or away from the body. The proximal segment of a joint in the upper extremity is usually stabilized by muscles, gravity, or its inertia, whereas the distal, relatively unconstrained, segment rotates.

Feeding oneself and throwing a ball are common examples of distal-on-proximal segment kinematics employed by the upper extremities. The upper extremities are certainly capable of performing proximal-on-distal segment kinematics, such as flexing and extending the elbows while one performs a pull-up.

The lower extremities routinely perform both proximal-on-distal *and* distal-on-proximal segment kinematics. These kinematics reflect, in part, the two primary phases of walking: the *stance phase*, when the limb is planted on the ground under the load of body weight, and the *swing phase*, when the limb is advancing forward. Many other activities, in addition to walking, use both kinematic strategies. Flexing the knee in preparation to kick a ball, for example, is a type of distal-on-proximal segment kinematics (see Fig. 1.6A). Descending into a squat position, in contrast, is an example of proximal-on-distal segment kinematics (see Fig. 1.6B). In the latter example, a relatively large demand is placed on the quadriceps muscle of the knee to control the gradual descent of the body.

The terms *open* and *closed kinematic chains* are frequently used in the physical rehabilitation literature and clinics to describe the concept of relative segment kinematics. A *kinematic chain* refers to a series of articulated segmented links, such as the connected pelvis, thigh, leg, and foot of the lower extremity. The terms "open" and "closed" are typically used to indicate whether the distal end of an extremity is fixed to the earth or some other immovable object. An *open kinematic chain* describes a situation in which the distal segment of a kinematic chain, such as the foot in the lower limb, is *not fixed* to the earth or another immovable object. The distal segment therefore is free to move (see Fig. 1.6A).

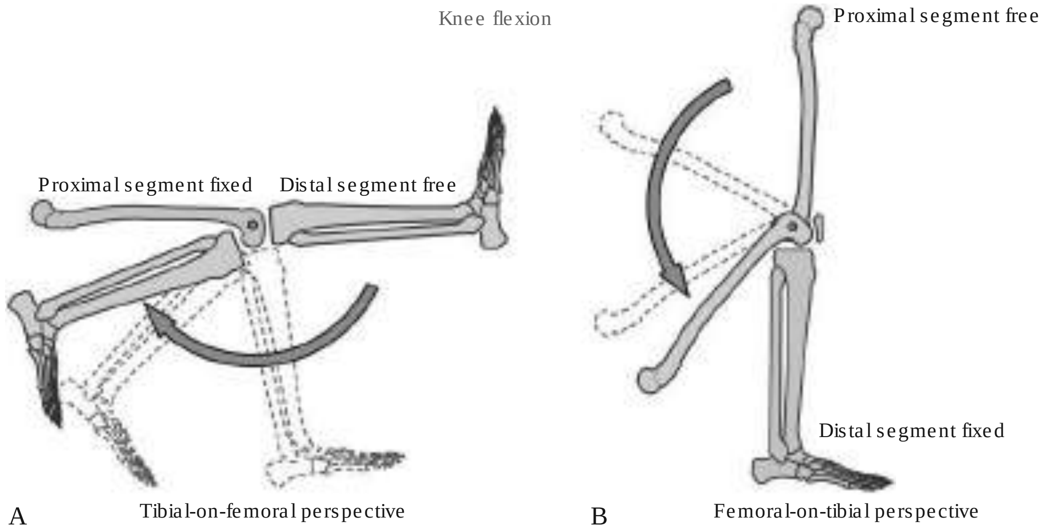


FIG. 1.6 Sagittal plane osteokinematics at the knee show an example of (A) distal-on-proximal segment kinematics and (B) proximal-on-distal segment kinematics. The axis of rotation is shown as a circle at the knee.

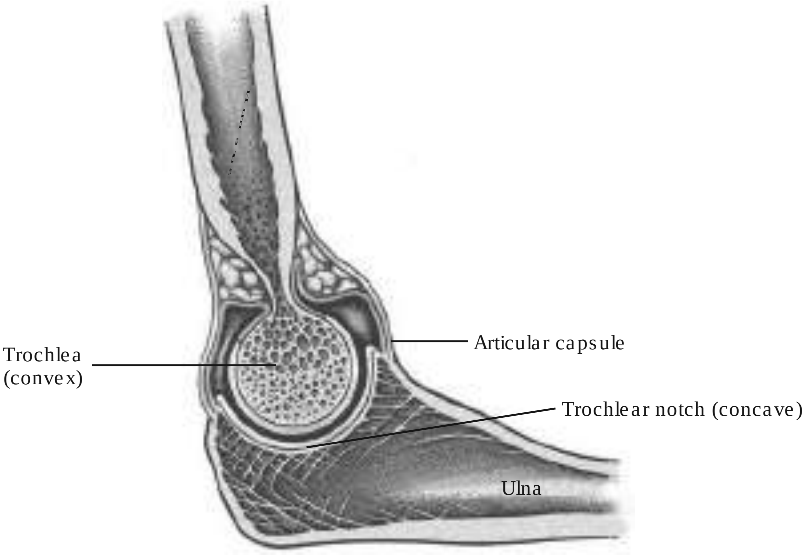


FIG. 1.7 The humero-ulnar joint at the elbow is an example of a convex-concave relationship between two articular surfaces. The trochlea of the humerus is convex, and the trochlear notch of the ulna is concave.

A *closed kinematic chain* describes a situation in which the distal segment of the kinematic chain is *fixed* to the earth or another immovable object. In this case the proximal segment is free to move (see Fig. 1.6B). These terms are employed extensively to describe methods of applying resistive exercise to muscles, especially to the joints of the lower limb.

Although very convenient terminology, the terms *open* and *closed kinematic chains* are often ambiguous. From a strict engineering perspective, the terms apply more to the *kinematic interdependence* of a series of connected rigid links, which is not exactly the same as the previous definitions given here. From this engineering perspective, the chain is "closed" if *both ends* are fixed to a common object, much like a closed circuit. In this case, movement of any one link requires a kinematic adjustment of one or more of the other links within the chain.

"Opening" the chain by disconnecting one end from its fixed attachment interrupts this kinematic interdependence. This more precise terminology does not apply universally across all health-related and engineering disciplines. Performing a one-legged partial squat, for example, is often referred to clinically as the movement of a closed kinematic chain. It could be argued, however, that this is a movement of an open kinematic chain because the contralateral leg is not fixed to ground (i.e., the circuit formed by the total body is open). To avoid confusion, this text uses the terms *open* and *closed kinematic chains* sparingly, and the preference is to explicitly state which segment (proximal or distal) is considered fixed and which is considered free.

Arthrokinematics

TYPICAL JOINT MORPHOLOGY

Arthrokinematics describes the motion that occurs *between the articular surfaces* of joints. As described further in Chapter 2, the shapes of the articular surfaces of joints range from flat to curved. Most joint surfaces, however, are at least slightly curved, with one surface being relatively convex and one relatively concave (Fig. 1.7). The convex-concave relationship of most articulations improves their congruency (fit), increases the surface area for dissipating contact forces, and helps guide the motion between the bones.

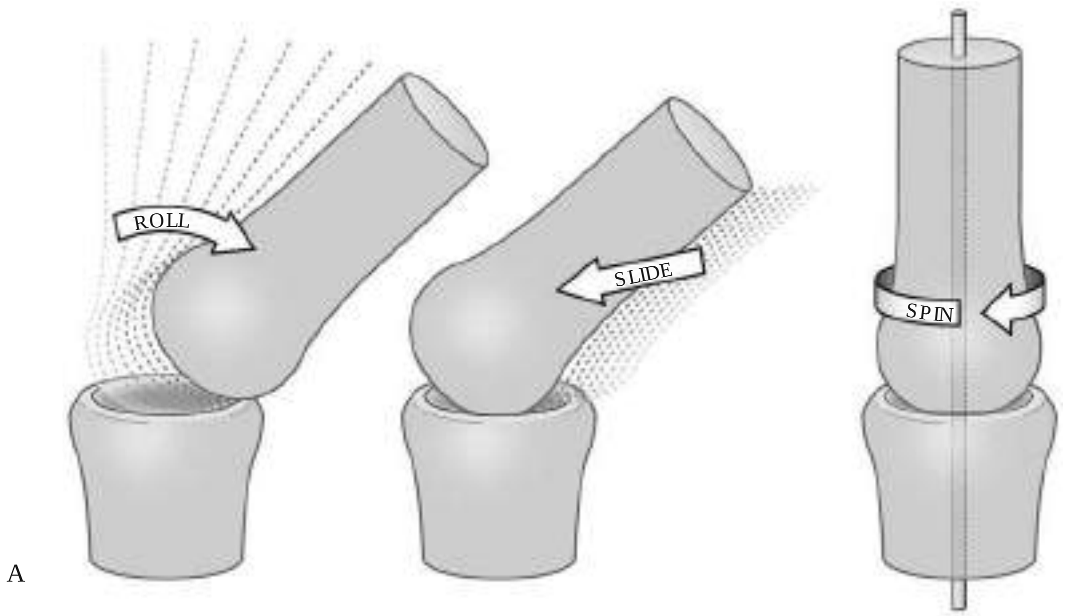
FUNDAMENTAL MOVEMENTS BETWEEN JOINT SURFACES

Three fundamental movements exist between curved joint surfaces: roll, slide, and, spin. These movements occur as a convex surface moves on a concave surface, and vice versa (Fig. 1.8). Although other terms are used, these are useful for visualizing the relative movements that occur within a joint. The terms are formally defined in Table 1.3.

Roll-and-Slide Movements

One primary way that a bone rotates through space is by a *rolling* of its articular surface against another bone's articular surface. The

Convex-on-concave arthrokinematics



Concave-on-convex arthrokinematics

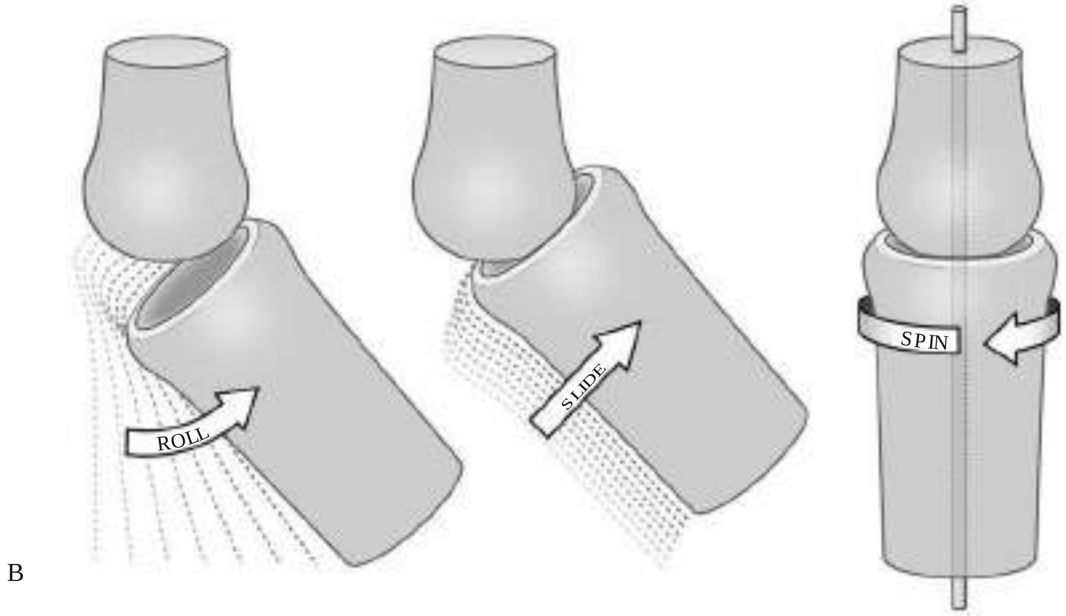


FIG. 1.8 Three fundamental arthrokinematics that occur between curved joint surfaces: roll, slide, and spin. A, Convex-on-concave movement. B, Concave-on-convex movement.

TABLE 1.3 **Three Fundamental Arthrokinematics: Roll, Slide, and Spin**

Movement	Definition	Analogy
Roll*	*Multiple points* along one rotating articular surface contact *multiple points* on another articular surface.	A tire rotating across a stretch of pavement
Slide†	A *single point* on one articular surface contacts *multiple points* on another articular surface.	A nonrotating tire skidding across a stretch of icy pavement
Spin	A *single point* on one articular surface rotates on a *single point* on another articular surface.	A toy top rotating on one spot on the floor

*Also termed rock.
†Also termed glide.

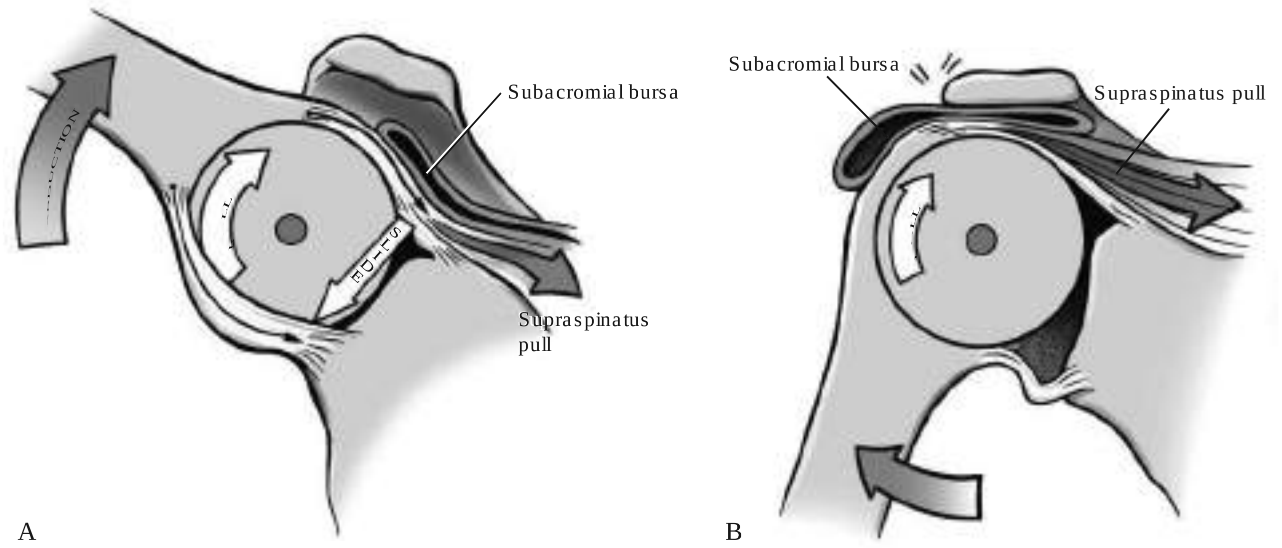


FIG. 1.9 Arthrokinematics at the glenohumeral joint during abduction. The glenoid fossa is concave, and the humeral head is convex. A, Roll-and-slide arthrokinematics typical of a convex articular surface moving on a relatively stationary concave articular surface. B, Consequences of a roll occurring without a sufficient offsetting slide.

motion is shown for a convex-on-concave surface movement at the glenohumeral joint in Fig. 1.9A. The contracting supraspinatus muscle rolls the convex humeral head against the slight concavity of the glenoid fossa. In essence, the roll directs the osteokinematic path of the abducting shaft of the humerus.

A rolling convex surface typically involves a concurrent, oppositely directed slide. As shown in Fig. 1.9A the inferior-directed *slide* of the humeral head offsets most of the potential superior migration of the rolling humeral head. The offsetting roll-and-slide kinematics are analogous to a tire on a car that is spinning on a sheet of ice. The potential for the tire to rotate forward on the icy pavement is offset by a continuous sliding of the tire in the opposite direction to the intended rotation. A classic pathologic example of a convex surface rolling *without* an offsetting slide is shown in Fig. 1.9B. The humeral head translates upward and impinges on the delicate tissues in the subacromial space. The migration alters the relative location of the axis of rotation, which may alter the effectiveness of the muscles that cross the glenohumeral joint.

As shown in Fig. 1.9A the concurrent roll-and-slide motion maximizes the angular displacement of the abducting humerus and minimizes the net translation between joint surfaces. This mechanism is particularly important in joints in which the articular surface area of the convex member exceeds that of the concave member.

Spin

Another primary way that a bone rotates is by a *spinning* of its articular surface against the articular surface of another bone. This occurs as the radius of the forearm spins against the capitulum of the humerus during pronation of the forearm (Fig. 1.10). Other examples include internal and external rotation of the 90-degree abducted glenohumeral joint, and flexion and extension of the hip. Spinning is the primary mechanism for joint rotation when the longitudinal axis of the moving bone intersects the surface of its articular mate at right angles.

Motions That Combine Roll-and-Slide and Spin Arthrokinematics

Several joints throughout the body combine roll-and-slide with spin arthrokinematics. A classic example of this combination occurs during flexion and extension of the knee. As shown during femoral-on-tibial knee extension (Fig. 1.11A), the femur spins internally slightly as the femoral condyle rolls and slides relative to the fixed (stationary) tibia. These arthrokinematics are also shown as the tibia extends relative to the fixed femur in Fig. 1.11B. In the knee the spinning motion that occurs with flexion and extension occurs automatically and is mechanically linked to the primary motion of extension. As described in Chapter 13, the obligatory spinning rotation is based on the shape of the articular surfaces at the knee. The conjunct rotation helps to securely lock the knee joint when fully extended.

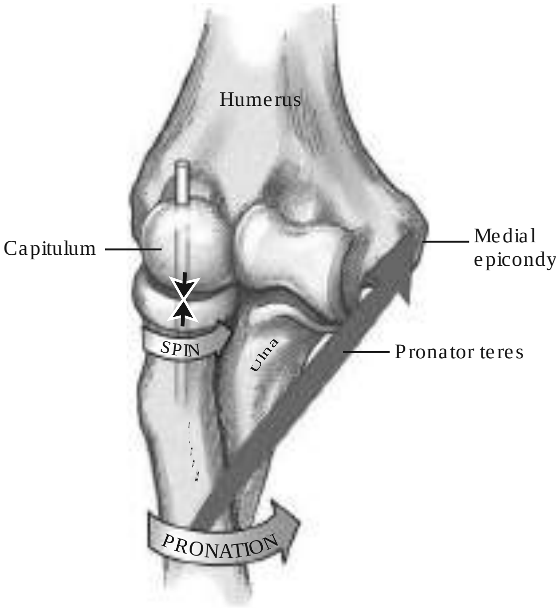


FIG. 1.10 Pronation of the forearm shows an example of a spinning motion between the head of the radius and the capitulum of the humerus. The pair of opposed short black arrows indicates compression forces between the head of the radius and the capitulum.

PREDICTING AN ARTHROKINEMATIC PATTERN BASED ON JOINT MORPHOLOGY

As previously stated, most articular surfaces of bones are either convex or concave. Depending on which bone is moving, a convex surface may rotate on a concave surface or vice versa (compare Fig. 1.11A with Fig. 1.11B). Each scenario presents a different roll-and-slide arthrokinematic pattern. As depicted in Figs. 1.11A and 1.9A for the shoulder, during a *convex-on-concave movement*, the convex surface rolls and slides in *opposite directions*. As previously described, the contradirectional slide offsets much of the translation tendency inherent to the rolling convex surface. During a *concave-on-convex movement*, as depicted in Fig. 1.11B, the concave surface rolls and slides in *similar directions*. These two principles are very useful for visualizing the arthrokinematics during a movement. In addition, the principles serve as a basis for some manual therapy techniques.[18] External forces may be applied by the clinician that assist or guide the natural arthrokinematics at the joint. For example, in certain circumstances, glenohumeral abduction can be facilitated by applying an inferior-directed force at the proximal humerus, simultaneously with an active-abduction effort. The arthrokinematic principles are based on the knowledge of the joint surface morphology.

Arthrokinematic Principles of Movement

- For a *convex-on-concave* surface movement, the convex member rolls and slides in *opposite* directions.
- For a *concave-on-convex* surface movement, the concave member rolls and slides in *similar* directions.

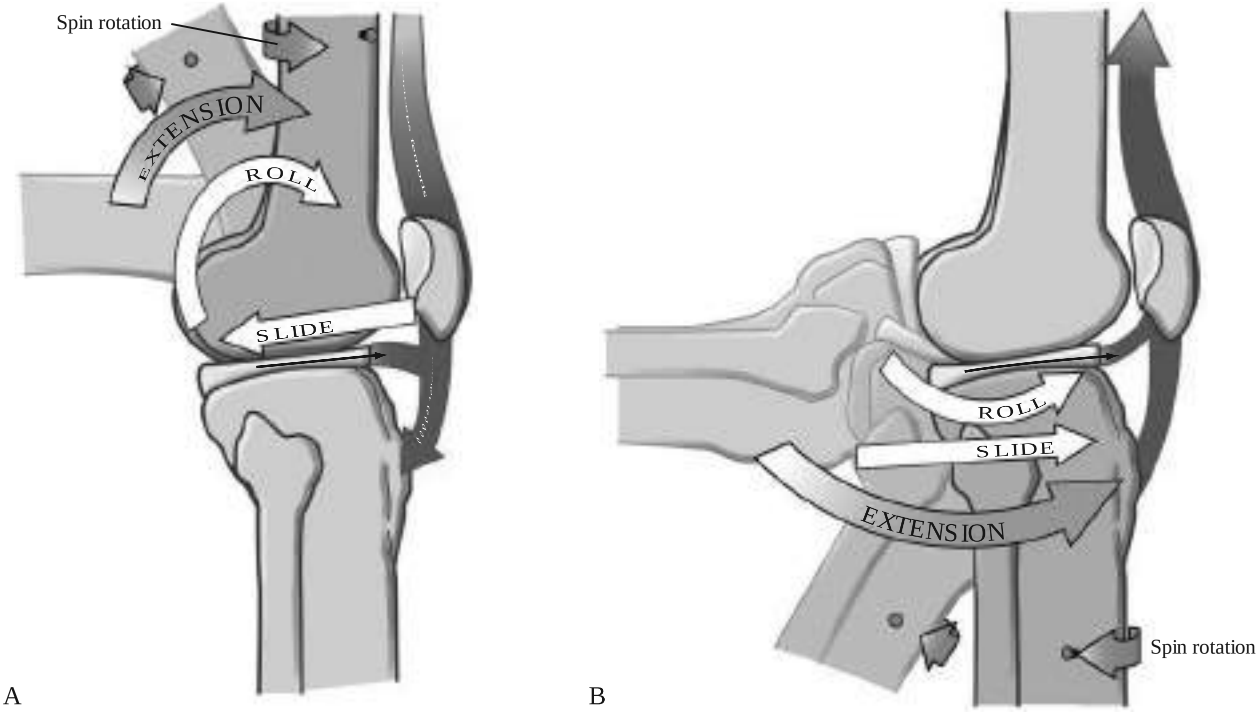


FIG. 1.11 Extension of the knee demonstrates a combination of roll-and-slide with spin arthrokinematics. The femoral condyle is convex, and the tibial plateau is slightly concave. A, Femoral-on-tibial (knee) extension. B, Tibial-on-femoral (knee) extension.

and extension occurs automatically and is mechanically linked to the primary motion of extension. As described in Chapter 13, the obligatory spinning rotation is based on the shape of the articular surfaces at the knee. The conjunct rotation helps to securely lock the knee joint when fully extended.

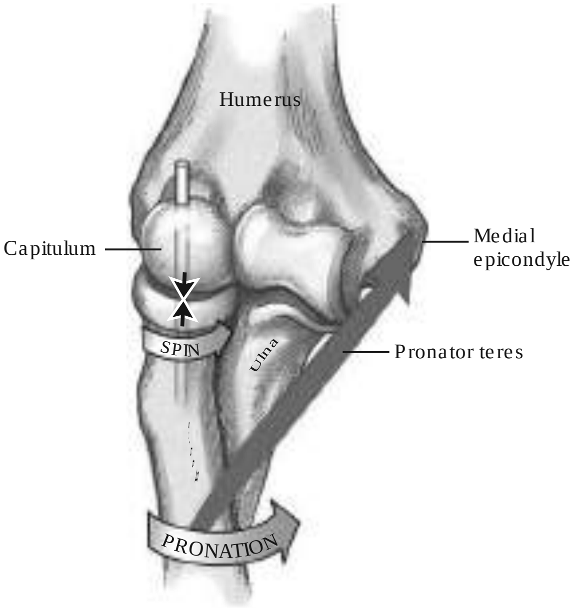


FIG. 1.10 Pronation of the forearm shows an example of a spinning motion between the head of the radius and the capitulum of the humerus. The pair of opposed short black arrows indicates compression forces between the head of the radius and the capitulum.

PREDICTING AN ARTHROKINEMATIC PATTERN BASED ON JOINT MORPHOLOGY

As previously stated, most articular surfaces of bones are either convex or concave. Depending on which bone is moving, a convex surface may rotate on a concave surface or vice versa (compare Fig. 1.11A with Fig. 1.11B). Each scenario presents a different roll-and-slide arthrokinematic pattern. As depicted in Figs. 1.11A and 1.9A for the shoulder, during a *convex-on-concave movement*, the convex surface rolls and slides in *opposite directions*. As previously described, the contradirectional slide offsets much of the translation tendency inherent to the rolling convex surface. During a *concave-on-convex movement*, as depicted in Fig. 1.11B, the concave surface rolls and slides in *similar directions*. These two principles are very useful for visualizing the arthrokinematics during a movement. In addition, the principles serve as a basis for some manual therapy techniques.[18] External forces may be applied by the clinician that assist or guide the natural arthrokinematics at the joint. For example, in certain circumstances, glenohumeral abduction can be facilitated by applying an inferior-directed force at the proximal humerus, simultaneously with an active-abduction effort. The arthrokinematic principles are based on the knowledge of the joint surface morphology.

Arthrokinematic Principles of Movement

- For a *convex-on-concave* surface movement, the convex member rolls and slides in *opposite* directions.
- For a *concave-on-convex* surface movement, the concave member rolls and slides in *similar* directions.

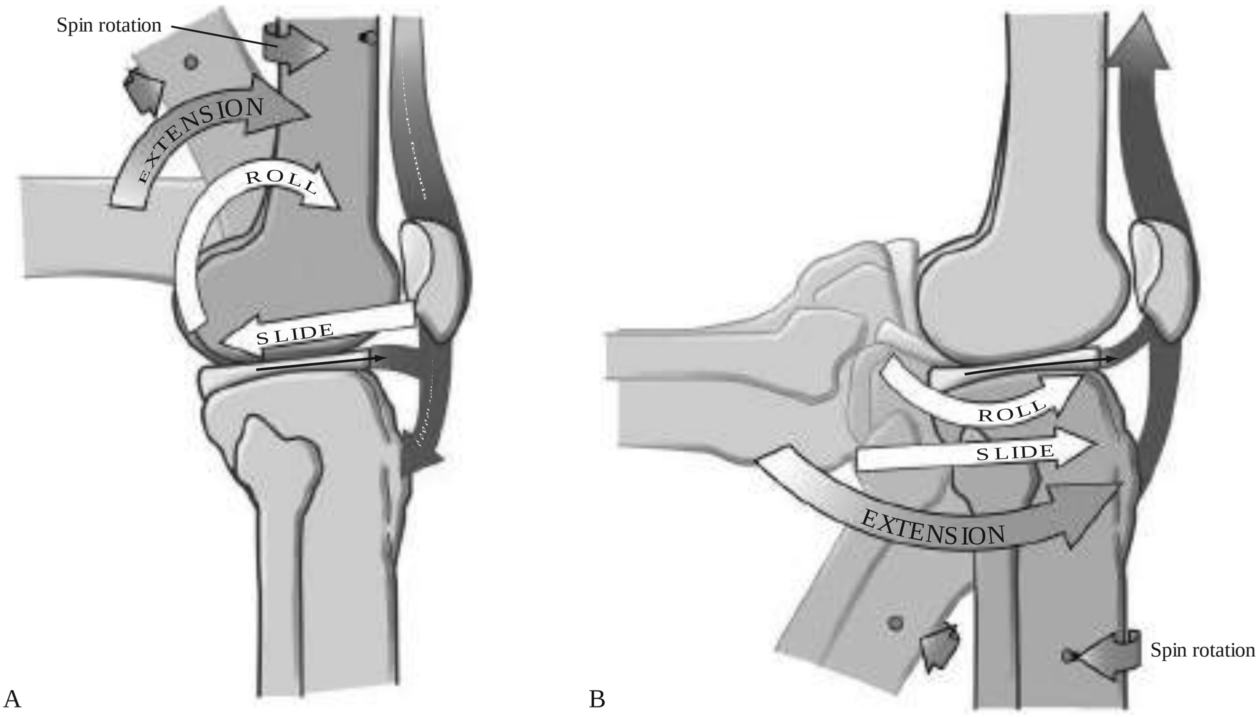


FIG. 1.11 Extension of the knee demonstrates a combination of roll-and-slide with spin arthrokinematics. The femoral condyle is convex, and the tibial plateau is slightly concave. A, Femoral-on-tibial (knee) extension. B, Tibial-on-femoral (knee) extension.

CLOSE-PACKED AND LOOSE-PACKED POSITIONS AT A JOINT

The pair of articular surfaces within most joints "fits" best in only one position, usually in or near the very end range of a motion. This position of maximal congruency is referred to as the joint's *close-packed position*.[21] In this position, most ligaments and parts of the capsule are pulled taut, providing an element of natural stability to the joint. Accessory movements are typically minimal in a joint's close-packed position.

For many joints in the lower extremity, the close-packed position is associated with a habitual function. At the knee, for example, the close-packed position includes full extension—a position that is typically approached while standing. The combined effect of the maximal joint congruity and stretched ligaments helps to provide transarticular stability to the knee.

All positions other than a joint's close-packed position are referred to as the joint's *loose-packed positions*. In these positions, the ligaments and capsule are relatively slackened, allowing an increase in accessory movements. The joint is generally least congruent near its midrange. In the lower extremity, the loose-packed positions of the major joints are biased toward flexion. These positions are generally not used during prolonged standing, but frequently are preferred by the patient during long periods of immobilization, such as extended bed rest.

KINETICS

Kinetics is a branch of the study of mechanics that describes the effect of forces on the body. The topic of kinetics is introduced here as it applies to the musculoskeletal system. A more detailed and mathematic approach to this subject matter is provided in Chapter 4.

From a kinesiologic perspective, a *force* can be considered as a push or pull that can produce, arrest, or modify movement. Forces therefore provide the ultimate impetus for movement and stabilization of the body. As described by Newton's second law, the quantity of a force (F) can be measured by the product of the mass (m) that receives the push or pull, multiplied by the acceleration (a) of the mass. The formula $F = ma$ shows that, given a constant mass, a force is directly proportional to the acceleration of the mass: measuring the force yields the acceleration of the body, and vice versa. A net force is zero when the acceleration of the mass is zero.

The standard international unit of force is the *newton (N):* $1\ \text{N} = 1\ \text{kg} \times 1\ \text{m/sec}^2$. The English equivalent of the newton is the pound (lb): $1\ \text{lb} = 1\ \text{slug} \times 1\ \text{ft/sec}^2$ (4.448 N = 1 lb).

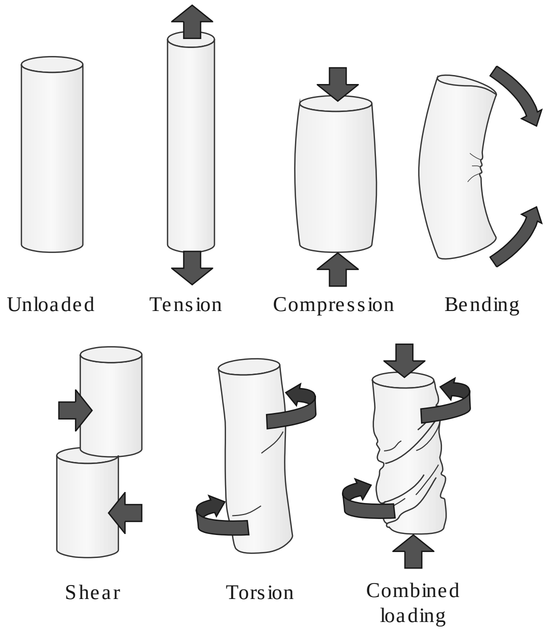


FIG. 1.12 The manner by which forces or loads are most frequently applied to the musculoskeletal system is shown. The combined loading of torsion and compression is also illustrated.

SPECIAL FOCUS 1.1

Body Weight Compared with Body Mass

A kilogram (kg) is a unit of mass that indicates the relative number of particles within an object. Strictly speaking, therefore, a kilogram is a measure of mass, not weight. Under the influence of gravity, however, a 1-kg mass weighs about 9.8 N (2.2 lb). This is the result of gravity acting to accelerate the 1-kg mass toward the center of earth at a rate of about 9.8 m/sec^2. Very often, however, the weight of a body is expressed in kilograms. The assumption is that the acceleration resulting from gravity acting on the body is constant and, for practical purposes, ignored. Technically, however, the weight of a person varies inversely with the square of the distance between the mass of the person and the center of the earth. A person on the summit of Mt. Everest at 29,035 ft (8852 m), for example, weighs slightly less than a person with identical mass at sea level. The acceleration resulting from gravity on Mt. Everest is 9.782 m/sec^2 compared with 9.806 m/sec^2 at sea level.

Musculoskeletal Forces

IMPACT OF FORCES ON THE MUSCULOSKELETAL SYSTEM: INTRODUCTORY CONCEPTS AND TERMINOLOGY

A force that acts on the body is often referred to generically as a *load*. Forces or loads that move, fixate, or otherwise stabilize the body also have the potential to deform and injure the body. The loads most frequently applied to the musculoskeletal system are illustrated in Fig. 1.12. (See the glossary at the end of this chapter for formal definitions.) Healthy tissues are typically able to partially resist changes in their structure and shape. The force that stretches a healthy ligament, for example, is met by an intrinsic tension generated within the elongated (stretched) tissue. Any tissue weakened by disease, trauma, or prolonged disuse may not be able to adequately resist the application of the loads depicted in Fig. 1.12. The proximal femur weakened by osteoporosis, for example, may fracture from the impact of a fall secondary to *compression or torsion (twisting), shearing*, or *bending* of the neck of the femur. Fracture may also occur in a severely osteoporotic hip after a very strong muscle contraction.

The ability of periarticular connective tissues to accept and disperse loads is an important topic of research within physical rehabilitation, manual therapy, and orthopedic medicine.[9,14]

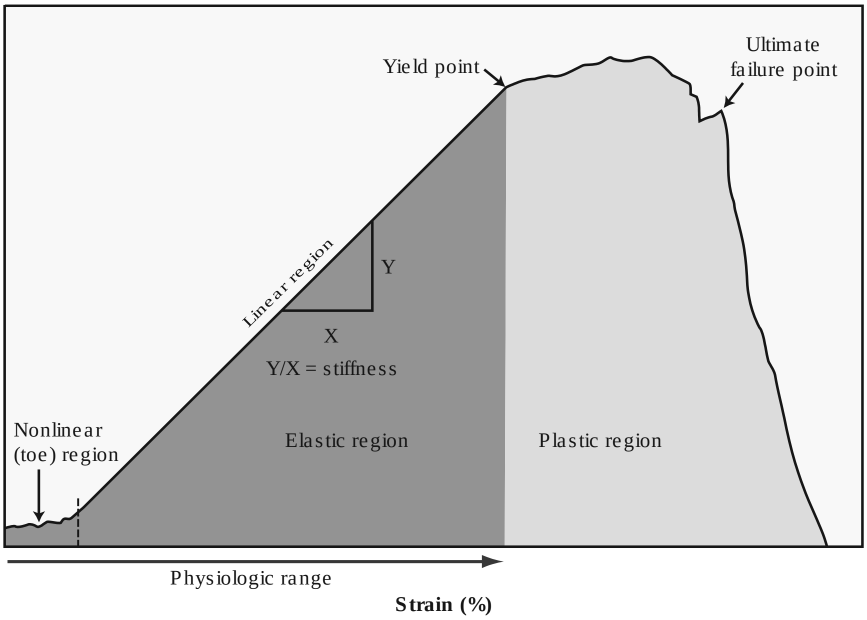


FIG. 1.13 The stress-strain relationship of an excised ligament that has been stretched to a point of mechanical failure (disruption).

Clinicians and scientists are very interested in how variables such as aging, trauma, altered activity or weight-bearing levels, or prolonged immobilization affect the load-accepting functions of periarticular connective tissues. One laboratory-based method of measuring the ability of a connective tissue to tolerate a load is to plot the force required to deform an excised tissue.[5] This type of experiment is typically performed using animal or human cadaver specimens. Fig. 1.13 shows a theoretical graph of the tension generated by a generic ligament (or tendon) that has been stretched to a point of mechanical failure. The vertical (Y) axis of the graph is labeled *stress,* a term that denotes the internal resistance generated as the ligament resists deformation, divided by its cross-sectional area. (The units of stress are similar to pressure: N/mm^2.) The horizontal (X) axis is labeled *strain,* which in this case is the percent increase in a tissue's stretched length relative to its original, preexperimental length.[20] (A similar procedure may be performed by *compressing* rather than stretching an excised slice of cartilage or bone, for example, and then plotting the amount of stress produced within the tissue.) Note in Fig. 1.13 that under a relatively slight strain (stretch), the ligament produces only a small amount of stress (tension). This *nonlinear* or "toe" region of the graph reflects the fact that the collagen fibers within the tissue are initially wavy or *crimped* and must be drawn taut before significant tension is measured.[14] Further elongation, however, shows a *linear relationship* between stress and strain. The ratio of the stress (Y) caused by an applied strain (X) in the ligament is a measure of its *stiffness* (often referred to as *Young's modulus*). All normal connective tissues within the musculoskeletal system exhibit some degree of stiffness. The clinical term "tightness" usually implies a pathologic condition of abnormally high stiffness.

The initial nonlinear and subsequent linear regions of the curve shown in Fig. 1.13 are often referred to as the *elastic region.* Ligaments, for example, are routinely strained within the lower limits of their elastic region. The anterior cruciate ligament, for example, is strained about 3–4% during common activities such as climbing stairs, pedaling a stationary bicycle, or squatting.[6,7,11] It is important to note that a healthy and relatively young ligament that is strained within the elastic zone returns to its original length (or shape) once the deforming force is removed. The area under the curve (in darker blue) represents *elastic deformation energy.* Most of the energy used to deform the tissue is released when the force is removed. Even in a static sense, elastic energy has an important function within joints. When stretched even a moderate amount into the elastic zone, ligaments and other connective tissues perform important joint stabilization functions.

A tissue that is elongated beyond its physiologic range eventually reaches its *yield point.* At this point, increased strain results in only marginal increased stress (tension). This physical behavior of an overstretched (or overcompressed) tissue is known as *plasticity.* The overstrained tissue has experienced *plastic deformation.* At this point microscopic failure has occurred and the tissue remains permanently deformed. The area under this region of the curve (in lighter blue) represents *plastic deformation energy.* Unlike elastic deformation energy, plastic energy is not recoverable in its entirety even when the deforming force is removed. As elongation continues, the ligament eventually reaches its *ultimate failure point,* the point when the tissue partially or completely separates and loses its ability to hold any level of tension. Most healthy tendons fail at about 8–13% beyond their prestretched length.[24]

The graph in Fig. 1.13 does not indicate the variable of *time* of load application. Tissues in which the physical properties associated with the stress-strain curve change as a function of time are considered *viscoelastic.* Most tissues within the musculoskeletal system demonstrate at least some degree of viscoelasticity. One phenomenon of a viscoelastic material is creep. As demonstrated by the tree branch in Fig. 1.14, *creep* describes a progressive strain of a material when exposed to a constant load over time. The phenomenon of creep helps to explain why a person is taller in the morning than at night. The constant compression caused by

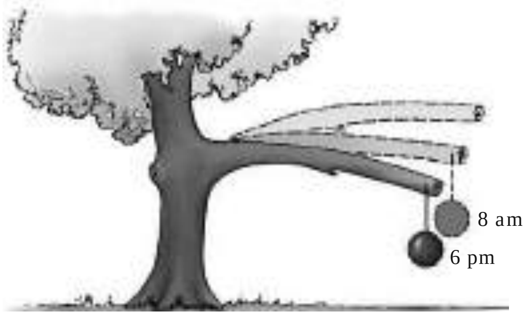


FIG. 1.14 The branch of the tree is demonstrating a time-dependent property of creep associated with a *viscoelastic material.* Hanging a load on the branch at 8 am creates an immediate deformation. By 6 pm, the load has caused additional deformation in the branch. (From Panjabi MM, White AA: *Biomechanics in the musculoskeletal system,* New York, 2001, Churchill Livingstone.)

body weight on the spine throughout the day literally squeezes a small amount of fluid out of the intervertebral discs. The fluid is reabsorbed at night while the sleeping person is in a non–weight-bearing position.

The stress-strain curve of a viscoelastic material is also sensitive to the *rate* of loading of the tissue. In general, the slope of a stress-strain relationship when placed under tension or compression increases throughout its elastic range as the rate of the loading increases.[20] The rate-sensitivity nature of viscoelastic connective tissues may protect surrounding structures within the musculoskeletal system. Articular cartilage in the knee, for example, becomes stiffer as the rate of compression increases,[19] such as during running. The increased stiffness affords greater protection to the underlying bone at a time when forces acting on the joint are greatest.

In summary, similar to building materials such as steel, concrete, and fiberglass, the periarticular connective tissues within the

SPECIAL FOCUS 1.2

Productive Antagonism: The Body's Ability to Convert Passive Tension into Useful Work

A stretched or elongated tissue within the body generally produces tension (i.e., a resistance force that opposes the stretch). In pathologic cases this tension may be abnormally large, thereby interfering with functional mobility. This textbook presents several examples, however, illustrating how relatively low levels of tension produced by stretched connective tissues (including muscle) perform useful functions. This phenomenon is called productive antagonism and is demonstrated for a pair of muscles in the simplified model in Fig. 1.15. As shown by the figure on the left, part of the energy produced by active contraction of muscle A is transferred and stored as elastic energy in the stretched connective tissues within muscle B. The elastic energy is released as muscle B actively contracts to drive the nail into the board (right illustration). Part of the contractile energy produced by muscle B is used to stretch muscle A, and the cycle is repeated.

This transfer and storage of energy between opposing muscles is useful in terms of overall metabolic efficiency. This phenomenon is often expressed in different ways by multi-articular muscles (i.e., muscles that cross several joints). Consider the rectus femoris, a muscle that flexes the hip and extends the knee. During the upward phase of jumping, for example, the rectus femoris contracts to extend the knee. At the same time, the extending hip stretches the active rectus femoris across the front of the hip. As a consequence, the overall shortening of the rectus femoris is minimized, which helps preserve useful passive tension within the muscle.

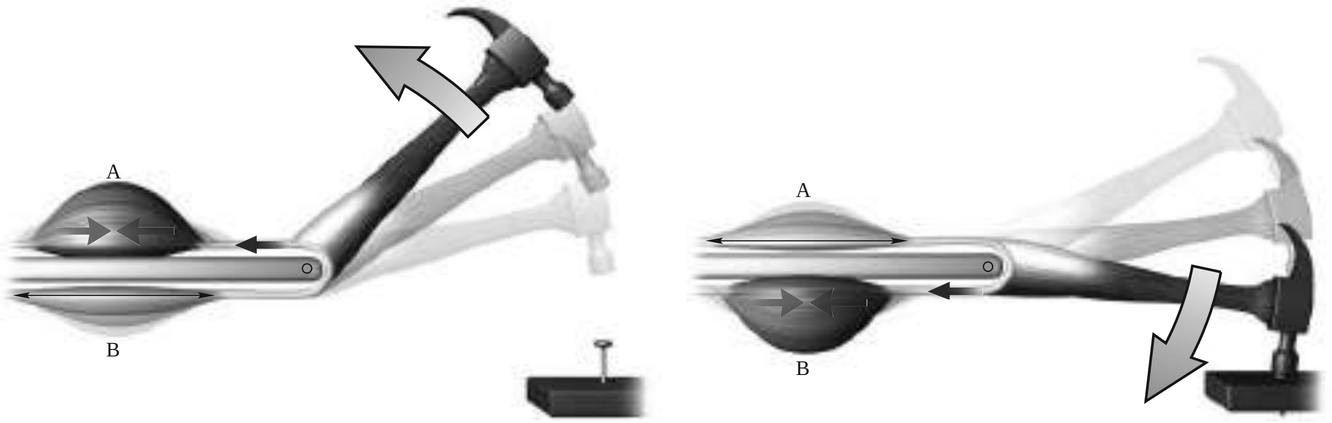


FIG. 1.15 A simplified model showing a pair of opposed muscles surrounding a joint. In the left illustration, muscle *A* is contracting to provide the force needed to lift the hammer in preparation to strike the nail. In the right illustration, muscle *B* is contracting, driving the hammer against the nail while simultaneously stretching muscle *A*. (Redrawn from Brand PW: *Clinical biomechanics of the hand,* St Louis, 1985, Mosby.)