passive joint motions enables the examiner to assess the tissue that is limiting the motion, detect pain, and make an estimate of the amount of motion. Goniometry is used to measure and document the amount of active and passive joint motion as well as abnormal fixed joint positions.

Following the examination of active and passive range of motion, resisted isometric muscle contractions, joint integrity and mobility tests, and special tests for specific body regions are used in conjunction with goniometry to help identify the injured anatomical structures. Tests to assess muscle performance and neurological function are often included. Diagnostic imaging procedures and laboratory tests may be needed. Functional outcome measures are often required for Medicare, Medicaid, and health insurance documentation.

Goniometric data used in conjunction with other information can provide a basis for the following:

- Determining the presence, absence, or change in impairment[1]
- Establishing a diagnosis
- Developing a prognosis, treatment goals, and plan of care
- Evaluating progress or lack of progress toward rehabilitative goals
- Modifying treatment
- Motivating the individual
- Researching the effectiveness of therapeutic techniques or regimens (for example, measuring outcomes following exercises, medications, and surgical procedures)
- Fabricating orthotics and adaptive equipment

Kinematics

Kinematics is the study of motion without regard for the forces that are creating the motion. When referring to the human body, kinematics describes the motion of bony segments including the type, direction, and magnitude of motion; location of the bony segment in space; and the rate of change or velocity of the segment. The three types of motion that a bony segment can undergo are translatory (linear displacement), rotary (angular displacement), or more often a combination of translatory and rotary motion.[2] In translatory motion, all points on a segment move in the same direction at the same time. In rotary motion, the bone spins around a fixed point. These three types of motion will be explained in more detail in the following subdivisions of kinematics: arthrokinematics and osteokinematics. In arthrokinematics, the focus is on how joint surfaces move and interact, whereas in osteokinematics, the focus is on movements of the shafts of bones.

Arthrokinematics

Motion at a joint occurs as the result of movement of one joint surface in relation to another joint surface. **Arthrokinematics** is the term used to refer to the movement of joint surfaces.[3,4] The movements of joint surfaces are described as slides (or glides), spins, and rolls. A **slide (glide),** which is a translatory motion, is the sliding of one joint surface over another, as when a braked wheel skids (Fig. 1.2). A **spin** is a rotary motion, similar to the spinning of a toy top. All points on the moving joint surface rotate around a fixed axis of motion (Fig. 1.3). A **roll** is also a rotary motion, similar to the rolling of the bottom of a rocking chair on the floor or the rolling of a tire on the road (Fig. 1.4).

In the human body, slides, spins, and rolls usually occur in combination with one another and result in angular movement of the shafts of the bones. The combination of the sliding and rolling is referred to as roll-gliding or roll-sliding[4] and allows for increased motion at a joint by postponing the joint

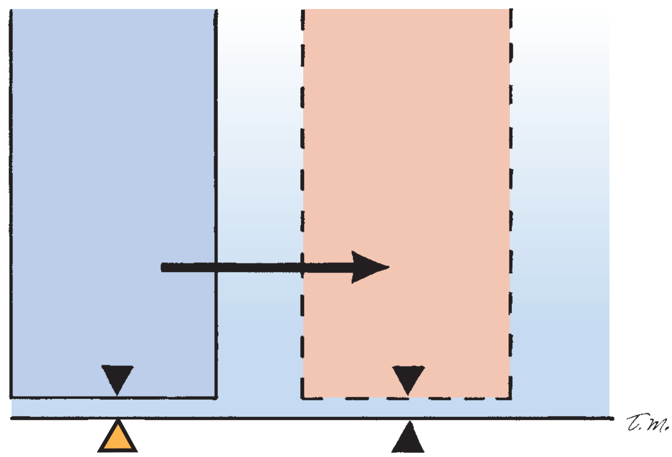

FIGURE 1.2 A slide (glide) is a translatory motion in which the same point on the moving joint surface comes in contact with new points on the opposing surface, and all the points on the moving surface travel the same amount of distance.

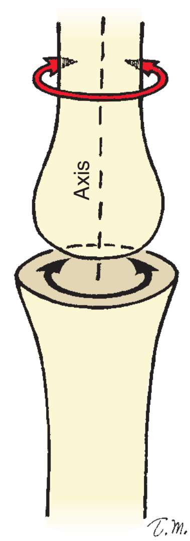

FIGURE 1.3 A spin is a rotary motion in which all the points on the moving surface rotate around a fixed central axis. The points on the moving joint surface that are closer to the axis of motion will travel a smaller distance than the points farther from the axis.

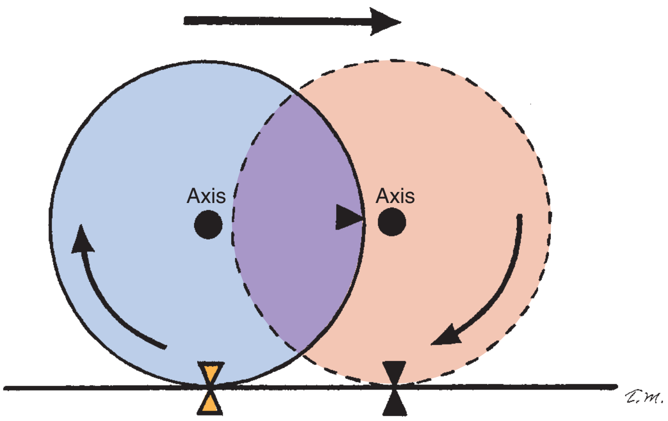

FIGURE 1.4 A roll is a rotary motion in which new points on the moving joint surface come in contact with new points on the opposing surface. The axis of rotation has also moved, in this case to the right.

compression and separation that would occur at either side of the joint during a pure roll. The direction of the rolling and sliding components of a roll-slide will vary depending on the shape of the moving joint surface. If a convex joint surface is moving, the convex surface will roll in the same direction as the angular motion of the shaft of the bone but will slide in the opposite direction (Fig. 1.5A). If a concave joint surface is moving, the concave surface will roll and slide in the same direction as the angular motion of the shaft of the bone (Fig. 1.5B).

Arthrokinematic motions are examined for amount of motion, tissue resistance at the end of the motion, and effect on the individual's symptoms.[5] The ranges of arthrokinematic motions are very small and cannot be measured with a goniometer or standard ruler. Instead, arthrokinematic motions are

TABLE 1.1 Arthrokinematic (Accessory/Joint Play) Joint Motion Grades

Grade	Joint Status
0	Ankylosed
1	Considerable hypomobility
2	Slight hypomobility
3	Normal
4	Slight hypermobility
5	Considerable hypermobility
6	Unstable

subjectively compared with the same motion on the contralateral side of the body or with an examiner's past experience testing people of similar age and gender as the individual. An ordinal grading scale of 0 to 6 is often used to describe the amount of arthrokinematic motions[6] (Table 1.1). These motions are also called accessory or joint play motions.

Osteokinematics

Osteokinematics refers to the gross movement of the shafts of bony segments rather than the movement of joint surfaces. The movements of the shafts of bones are usually described in terms of the rotary or angular motion produced, as if the movement occurs around a fixed axis of motion. Goniometry measures the angles created by the rotary motion of the shafts of the bones. Some translatory shifting of the axis of motion usually occurs during movement; however, most clinicians find the description of osteokinematic movement in terms of

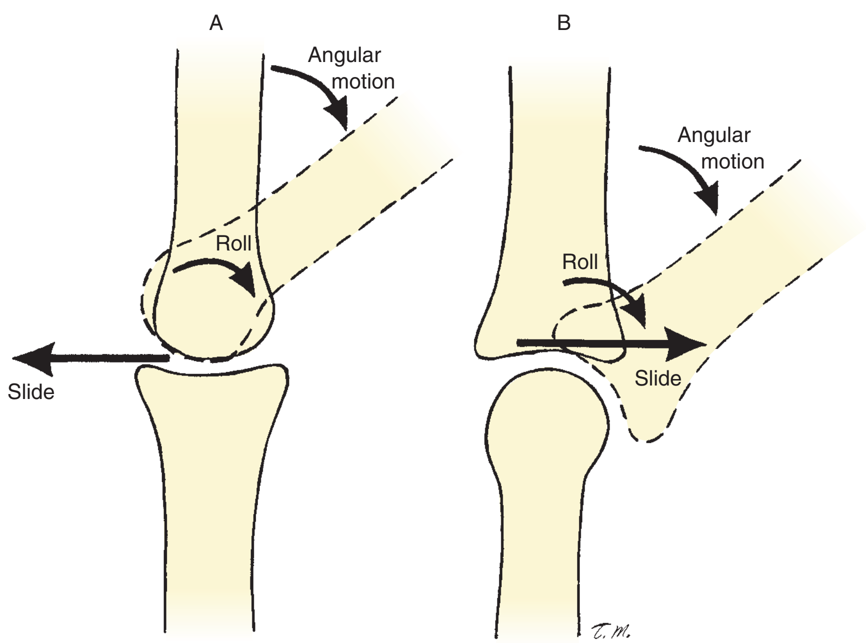

FIGURE 1.5 (A) If the joint surface of the moving bone is convex, sliding is in the opposite direction to the rolling and angular movement of the bone. (B) If the joint surface of the moving bone is concave, sliding is in the same direction as the rolling and angular movement of the bone.

just rotary motion to be sufficiently accurate and use goniometry to measure osteokinematic movements.

Planes and Axes

Osteokinematic motions are classically described as taking place in one of the three **cardinal planes** of the body (sagittal, frontal, transverse) around three corresponding **axes** (medial–lateral, anterior–posterior, vertical). The three planes lie at right angles to one another, whereas the three axes lie at right angles both to one another and to their corresponding planes.

The **sagittal plane** proceeds from the anterior to the posterior aspect of the body. The median sagittal plane divides the body into right and left halves.[7] The motions of flexion and extension occur in the sagittal plane (Fig. 1.6). The axis around which the motions of flexion and extension occur may be envisioned as a line that is perpendicular to the sagittal plane and proceeds from one side of the body to the other. This axis is called a **medial–lateral axis.** All motions in the sagittal plane take place around a medial–lateral axis.

The **frontal plane** proceeds from one side of the body to the other and divides the body into front and back halves. The motions that occur in the frontal plane are abduction and adduction (Fig. 1.7). The axis around which the motions of abduction and adduction take place is an **anterior–posterior axis.** This axis lies at right angles to the frontal plane and proceeds from the anterior to the posterior aspect of the body. Therefore, the anterior–posterior axis lies in the sagittal plane.

The **transverse plane** is horizontal and divides the body into upper and lower portions. The motion of rotation occurs in the transverse plane around a vertical axis (Fig. 1.8). The **vertical axis** lies at right angles to the transverse plane and proceeds in a cranial to caudal direction.

The osteokinematic motions described previously are considered to occur in a single plane around a single axis. Combination motions such as circumduction (flexion–abduction–extension–adduction) are possible at many joints, but because of the limitations imposed by the uniaxial design of the measuring instrument, only motion occurring in a single plane can be measured in goniometry.

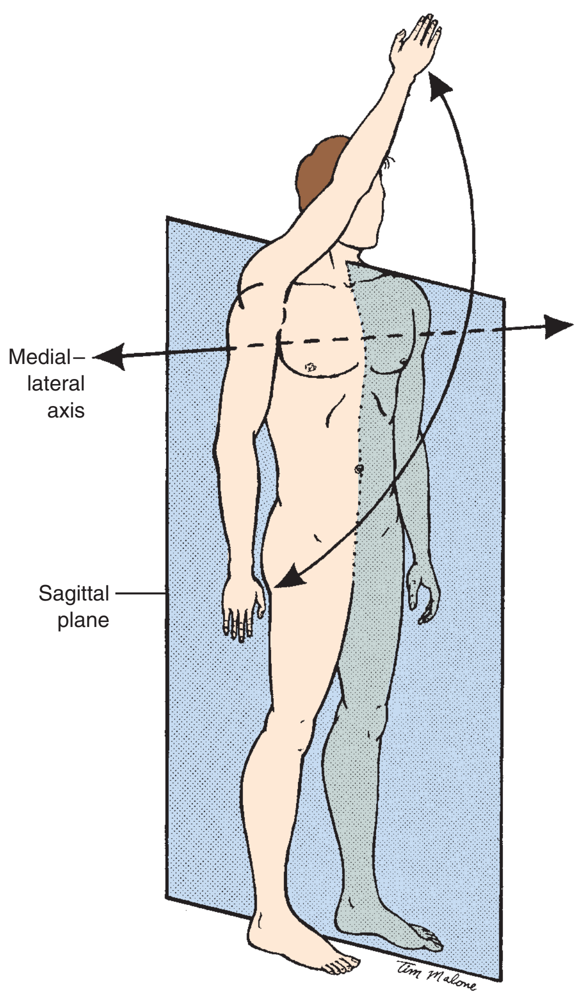

FIGURE 1.6 The shaded areas indicate the sagittal plane. This plane proceeds from the anterior aspect of the body to the posterior aspect. Motions in this plane, such as flexion and extension of the upper and lower extremities, take place around a medial–lateral axis.

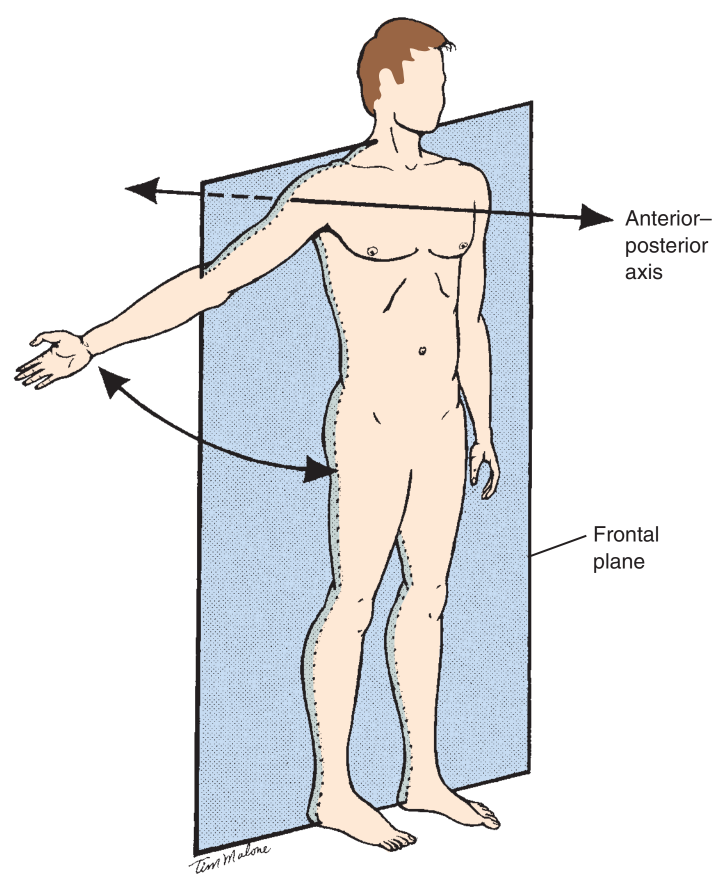

FIGURE 1.7 The frontal plane, indicated by the shaded area, proceeds from one side of the body to the other. Motions in this plane, such as abduction and adduction of the upper and lower extremities, take place around an anterior–posterior axis.

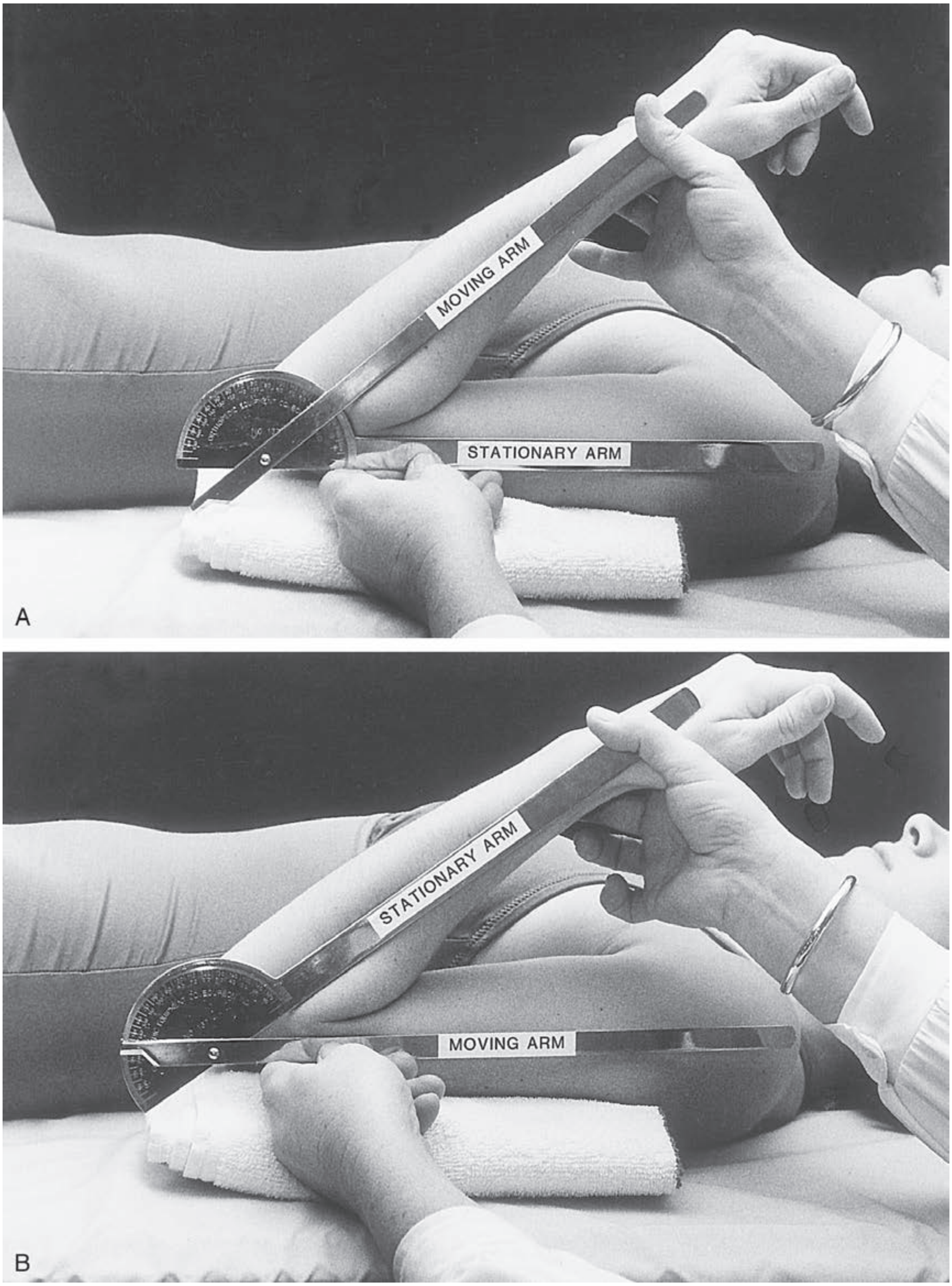

FIGURE 2.10 (A) When the examiner uses a half-circle goniometer to measure left elbow flexion, aligning the moving arm with the forearm causes the pointer to move beyond the goniometer body, which makes it impossible to read the scale. (B) Reversing the arms of the instrument so that the stationary arm is aligned parallel to the distal part and the moving arm is aligned parallel to the proximal part causes the pointer to remain on the body of the goniometer, enabling the examiner to read the scale along the pointer.

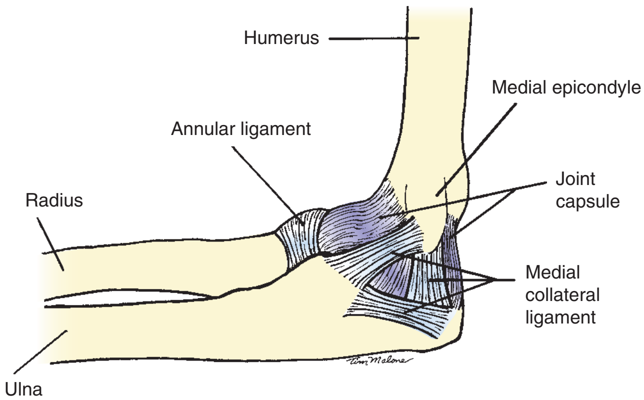

FIGURE 5.3 A medial view of the right elbow showing the medial (ulnar) collateral ligament, annular ligament, and joint capsule.

have found the angle of the left arm to be slightly greater than that of the right.[5] A carrying angle that is greater (more acute) than average is called "excessive cubitus valgus," whereas an angle that is less than average is called "cubitus varus."[7]

Osteokinematics

The humeroulnar and humeroradial joints have 1 degree of freedom; flexion–extension occurs in the sagittal plane around a medial–lateral (coronal) axis. In elbow flexion and extension, the axis of motion lies approximately through the center of the trochlea.[3] There is a slight amount of axial rotation and side-to-side motion of the ulnar during flexion and extension; therefore, the term *modified* hinge is best used to describe the elbow joint.[1,8,9]

Arthrokinematics

At the humeroulnar joint, posterior sliding of the concave trochlear notch of the ulna on the convex trochlea of the humerus continues during extension until the ulnar olecranon process enters the humeral olecranon fossa. In flexion, the ulna slides anteriorly along the humerus until the coronoid process of the ulna reaches the floor of the coronoid fossa of the humerus or until soft tissue in the anterior aspect of the elbow blocks further flexion.

At the humeroradial joint, the concave radial head slides posteriorly on the convex surface of the capitulum during extension. In flexion, the radial head slides anteriorly until the rim of the radial head enters the radial fossa of the humerus.

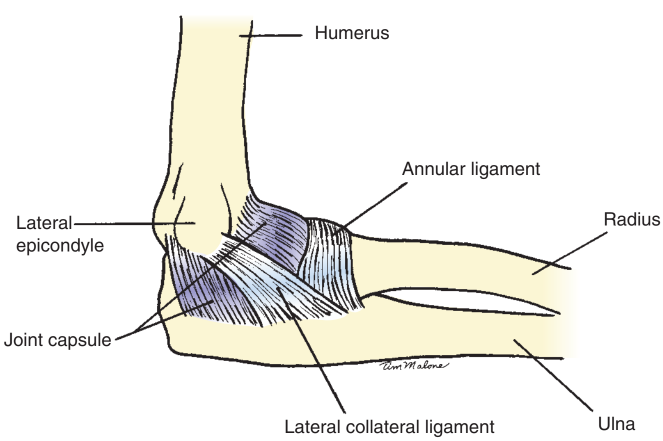

FIGURE 5.4 A lateral view of the right elbow showing the lateral (radial) collateral ligament, annular ligament, and joint capsule.

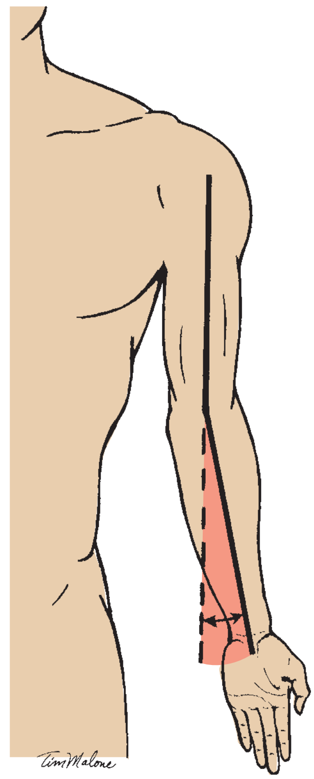

FIGURE 5.5 An anterior view of the right upper extremity showing the carrying angle between the longitudinal midline of the humerus and forearm.

Capsular Pattern

Most authorities agree that the range of motion (ROM) in flexion is more limited than it is in extension.[10–12] Only in severe cases would supination and pronation be slightly limited.[10] The literature varies as to the proportions of limitation in the capsular pattern for the elbow. For example, according to Cyriax 30 degrees of limitation in flexion would typically correspond to about 10 degrees of limitation in extension.[10] Kaltenborn notes that "with flexion limited to 90 degrees (60-degree limitation) there is only 10 degrees of limited extension."[11]

Superior and Inferior Radioulnar Joints

The ulnar portion of the superior radioulnar joint includes both the radial notch located on the lateral aspect of the proximal ulna and the annular ligament (Fig. 5.6). The radial notch and the annular ligament form a concave joint surface. The radial aspect of the joint is the convex head of the radius.

The ulnar component of the inferior radioulnar joint is the convex ulnar head (see Fig. 5.6). The opposing articular surface is the ulnar notch of the radius.

The interosseous membrane, a broad sheet of collagenous tissue linking the radius and ulna, provides stability for both joints (Fig. 5.7). The following three structures provide stability for the superior radioulnar joint: the annular ligament, quadrate ligament, and oblique cord. Stability of the inferior radioulnar joint is provided by the articular disc and the anterior and posterior radioulnar ligaments (Fig. 5.8).[1]

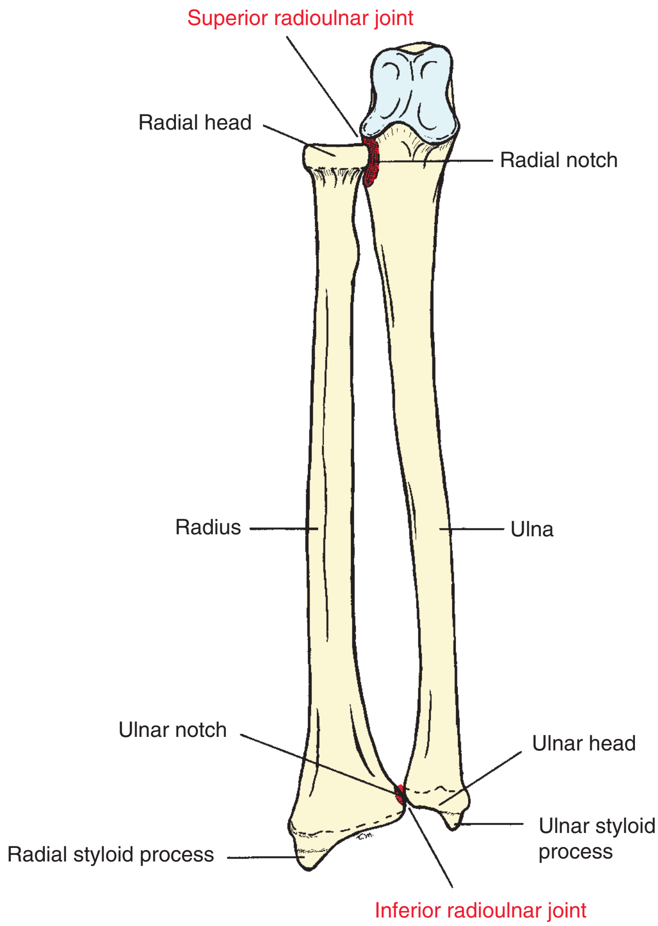

FIGURE 5.6 Anterior view of the superior and inferior radioulnar joints of the right forearm.

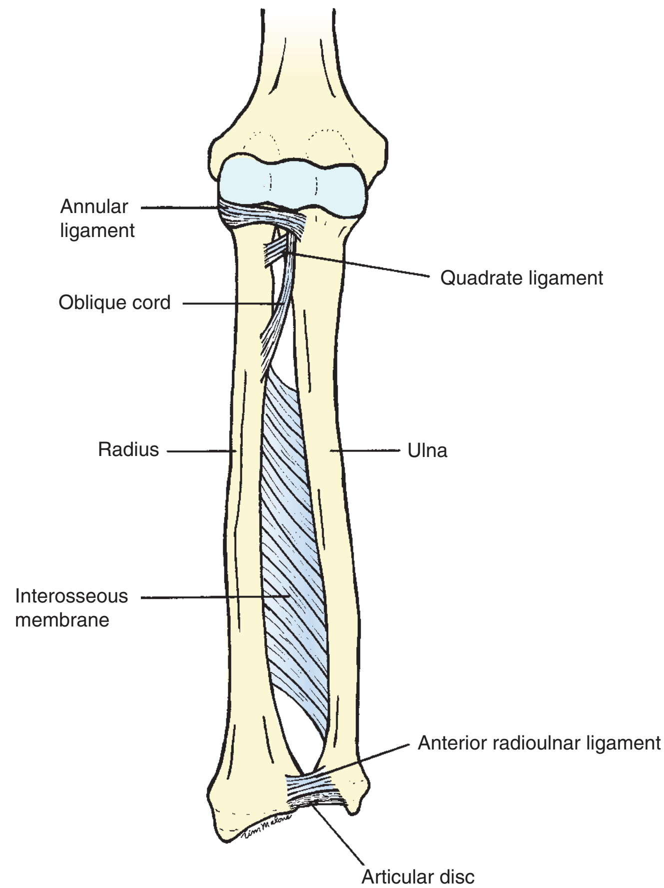

FIGURE 5.7 Anterior view of the superior and inferior radioulnar joints showing the annular ligament, quadrate ligament, oblique cord, interosseous membrane, anterior radioulnar ligament, and articular disc.

Osteokinematics

The superior and inferior radioulnar joints are mechanically linked. Therefore, motion at one joint is always accompanied by motion at the other joint. The axis for motion is a longitudinal axis extending from the radial head to the ulnar head. The mechanically linked synovial joints have 1 degree of freedom, permitting the motions of pronation and supination in the transverse plane when the individual is standing in anatomical position. However, pronation and supination are usually measured with the elbow flexed to 90 degrees to isolate the motions at the forearm and prevent rotation from also occurring at the glenohumeral joint. When the elbow is flexed to 90 degrees, pronation and supination occur in the frontal plane around an anterior–posterior axis. In pronation, the radius crosses over the ulna, whereas in supination the radius and ulna lie parallel to each other.

Arthrokinematics

At the superior radioulnar joint, the convex rim of the radial head spins within the annular ligament and the concave radial notch of the ulna during pronation and supination. The articular surface on the radial head spins posteriorly during pronation and anteriorly during supination.

At the inferior radioulnar joint, the concave surface of the ulnar notch on the radius slides over the ulnar head. The concave articular surface of the radius slides anteriorly (in the same direction as the hand) during pronation and slides posteriorly (in the same direction as the hand) during supination.

Capsular Pattern

The capsular pattern is an equal limitation of supination and pronation according to Cyriax and Cyriax[10] and Kaltenborn.[11]

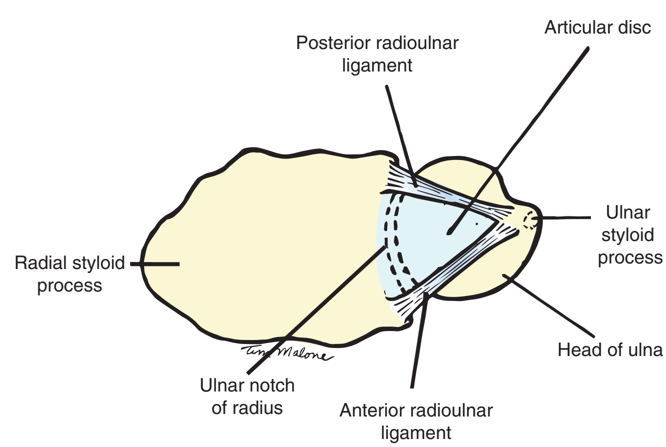

FIGURE 5.8 Distal aspect of the inferior radioulnar joint showing the articular disc (also called the triangular fibrocartilage) and radioulnar ligaments.

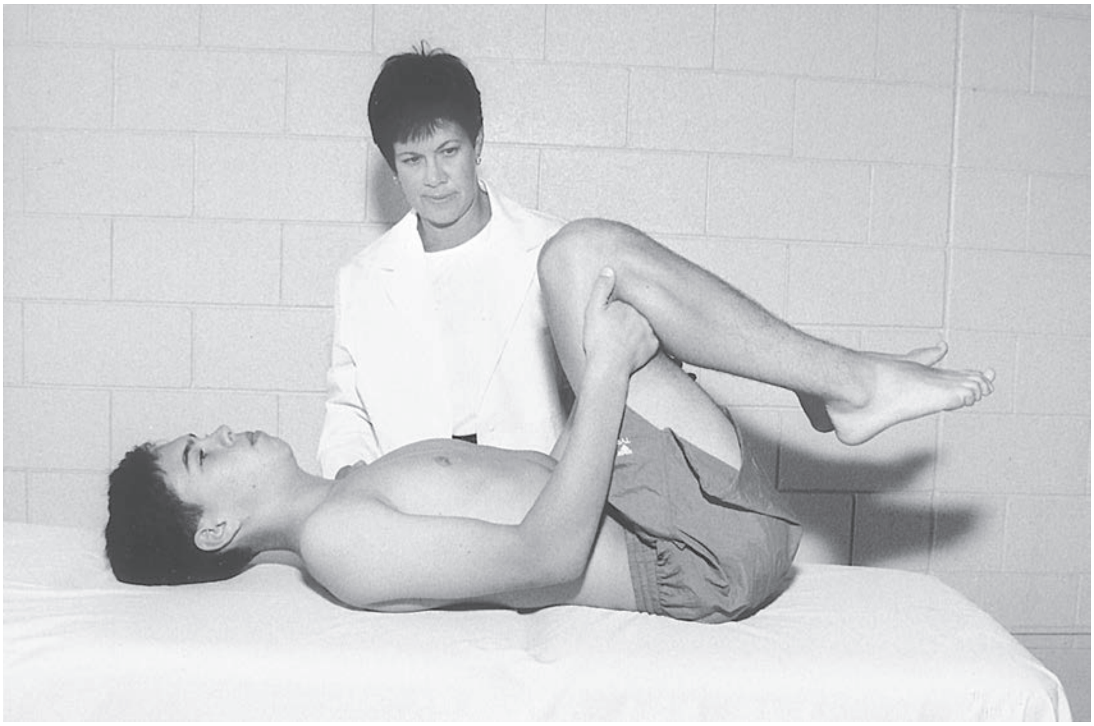

FIGURE 8.30 The starting position for testing the length of the hip flexors. Both knees and hips are flexed so that the low back and pelvis are flat on the examining table.

Stabilization

Either the examiner or the individual holds the hip not being tested in flexion (knee toward the chest) to maintain the low back and pelvis flat against the examining table. If the individual cannot reach the thigh, then a towel or sheet placed behind the knee can be used to hold the thigh in flexion.

Testing Motion

Passively extend the hip being tested by slowly lowering the thigh toward the examining table. Be sure the lower extremity remains in the sagittal plane by keeping the hip from rotating, abducting, or adducting. The examiner confirms that the thigh and lower leg are relaxed and not being actively held in flexion. Often individuals require extra cues to relax the muscles in the limb being tested. See Figures 8.31 and 8.32.

FIGURE 9.16 End of the testing motion for the length of the right hamstring muscles.

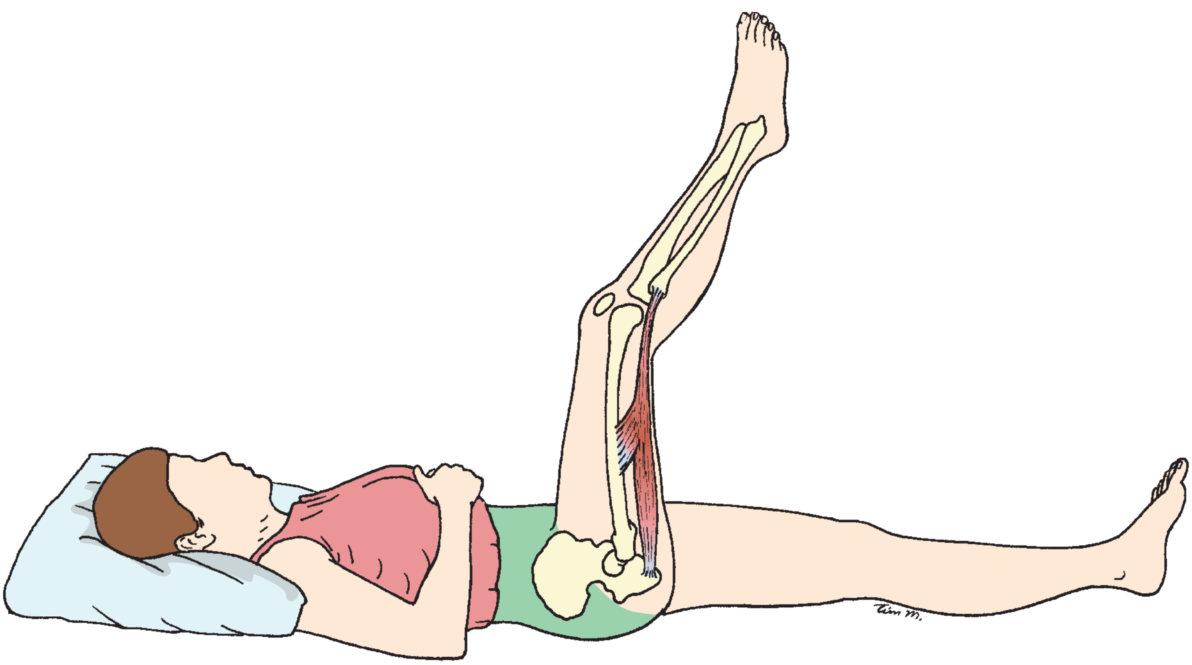

FIGURE 9.17 A lateral view of the right lower extremity shows the hamstring muscles being stretched over the hip and knee joints at the end of the testing motion.

TABLE 9.3 Knee Range of Motion in Infants and Young Children 0 to 12 Years of Age: Normal Values in Degrees

	Broughton et al[27]		Wanatabe et al[26]	Boone[28]	
Age **Sample**	**3 mo** ***n* = 57**	**6 mo** ***n* = 57**	**0–2 yr** ***n* = 109**	**1–5 yr** ***n* = 19**	**6–12 yr** ***n* = 17**
Motion	***Mean (SD)***	***Mean (SD)***	***Range of Means***	***Mean (SD)***	***Mean (SD)***
Flexion	145.5 (5.3)	141.7 (6.3)	148–159	141.7 (6.2)	147.1 (3.5)
Extension	10.7 (5.1)*	3.3 (4.3)*	5.0†	5.4 (3.1)†	0.4 (0.9)

SD = standard deviation.

*Indicates extension limitations.

†Indicates extension beyond 0 degrees.

10 degrees of knee extension beyond 0 as one of the criteria of joint laxity. Cheng, Chan, and Hui,[30] in a study of 2,360 Chinese children, found that the average of 16 degrees of knee extension beyond 0 in children of 3 years of age decreased to 7 degrees by the time the children reached 9 years of age.

Steinberg and colleagues,[31] in a study of 1,320 female dancers between the ages of 8 and 16 years of age and a control group of 226 nondancers of similar age, found that knee flexion ROM showed a small but significant decrease with increasing age in both groups. The authors suggested that the decreases in ROM might be related to a general increase in circumference in thigh and leg muscles that developed as the group matured and as subcutaneous fat was deposited. However, the decrease in ROM in nondancers appeared to be larger (15 degrees) than in dancers, which might be accounted for by the fact that the dancers were probably more active than the nondancers.

Soucie and colleagues[32] obtained bilateral passive knee ROM measurements on males and females in each of seven age-groups for a total of 674 healthy male and female individuals with a mean age of 33 years. Subjects were predominately white and included slightly more females than males. The authors found that joint ROM tended to decline with advancing age with the greatest difference between children (aged 2 to 8 years) and all other age-groups. The largest age-related difference between young and old was a 15-degree difference in mean knee flexion ROM between the 2-year-old group and the group aged 45 to 69.[32]

Also, a comparison of knee extension beyond 0 mean values for the group aged 13 to 19 years can be found in Table 9.4. Table 9.3 has extension values for the group aged 1 to 5 years, which demonstrates the decrease in knee extension beyond 0 that occurs in childhood.

Walker and colleagues[33] studied active ROM of the extremity joints in 30 men and 30 women (ranging in age from 60 to 84 years) from recreational centers. No differences were found in knee ROM between subjects aged 60 to 69 years and subjects aged 75 to 84 years. However, average values indicated that the subjects had an extension limitation (inability to attain a neutral 0-degree starting position). This finding was similar to the loss of extension noted at the hip, elbow, and first metatarsophalangeal joints. The 2-degree extension limitation found at the knee was much smaller than that found at the hip joint. According to the American Association of Orthopaedic Surgeons (AAOS) handbook,[34] extension limitations of 2 degrees are considered normal in adults. Extension limitations greater than 5 degrees in adults may be considered as knee flexion contractures. These contractures often occur in the elderly because of disease, sedentary lifestyles, and the effects of the aging process on connective tissues.

TABLE 9.4 Age Effects on Knee Flexion in Individuals 2 to 74 Years of Age: Mean Values in Degrees

	Soucie[32]*	Boone[28]		Roach and Miles[10]	
Age **Sample**	**2–8 yr** ***n* = 39**	**13–19 yr** ***n* = 17**	**20–29 yr** ***n* = 19**	**40–59 yr** ***n* = 727**	**60–74 yr** ***n* = 523**
Motion	***Mean (SD)***	***Mean (SD)***	***Mean (SD)***	***Mean (SD)***	***Mean (SD)***
Flexion	152.6 (4.5)	142.9 (3.7)	140.2 (5.2)	132.0 (11.0)	131.0 (11.0)
Extension	5.4 (4.9)	0.0 (0.0)	0.4 (0.9)		

SD = Standard deviation.

*Females.

Mollinger and Steffan[35] used a universal goniometer (UG) to assess knee ROM among 112 nursing home residents with an average age of 83 years. The authors found that only 13% of the subjects had full (0-degree) passive knee extension bilaterally. Thirty-seven of the 112 subjects (33%) had bilateral knee extension limitations of 5 degrees or less, which the AAOS considers normal in older adults. Forty-seven subjects (42%) had greater than 10 degrees of limitations in extension (flexion contractures). Residents with a 30-degree loss of knee extension had an increase in resistance to passive motion and a loss of ambulation.

Steultjens and coworkers[36] found knee flexion contractures in 31.5% of 198 patients with osteoarthritis of the knee or hip. (It should be noted that these authors considered knee flexion contractures as an inability to attain the horizontal 0 starting position for measuring flexion.) Flexion contractures of the knee or hip or both were found in 73% of patients. Generally, a decrease in active assistive ROM was associated with an increase in disability but was motion specific. The motions that had the strongest relationship with disability were knee flexion, hip extension, and lateral rotation. Ersoz and Ergun[37] found that in a group of 44- to 76-year-old patients with primary knee osteoarthritis, 33 out of the 40 knees tested (82.5%) had extension limitations ranging from 1 to 14 degrees.

Despite the knee flexion contractures found in the elderly by Mollinger and Steffan,[35] many elderly individuals appear to have at least a functional flexion ROM. Escalante and coworkers[38] used a UG to measure knee flexion passive ROM in 687 community-dwelling elderly subjects between the ages of 65 and 79 years. More than 90 degrees of knee flexion was found in 619 (90.1%) of the subjects. The authors used a cut-off value of 124 degrees of flexion as being within normal limits. Subjects who failed to reach 124 degrees of flexion were classified as having an abnormal ROM. Using this criterion, 76 (11%) right knees and 63 (9%) left knees were below this value and thus had abnormal (limited) passive ROM in flexion. Nonaka and colleagues[39] examined age-related changes at the hip and knee in 77 healthy male volunteers aged 15 to 73 years. The authors found that passive ROM of the hip joint decreased with increasing age but knee joint passive ROM remained unchanged. However, interactive motion of the hip and knee showed an age-related reduction, which the authors attributed to shortening of muscle and connective tissue.

Macedo and Magee[40] took goniometric passive ROM measurements of the ankle, knee, hip, shoulder, elbow, and wrist joints in 90 healthy Caucasian women ages 18 to 59. These authors found that only 11 of the tested motions, including knee flexion, showed that increasing age was associated with statistically significant decreases in passive ROM but that the decreases were small.

Gender

In general, it appears that females have greater knee ROM and more knee joint laxity than their male counterparts. Soucie and colleagues[32] found that in addition to age differences, the following gender difference was present: Females had greater joint mobility in all age-groups in nearly all joints compared with males. The authors also found some evidence to support the finding that the joint mobility index increases in females after they enter puberty.

Beighton, Solomon, and Soskolne[29] defined more than 10 degrees of knee extension beyond 0 as hyperextension and included this criterion in a study of joint laxity in 1,081 males and females. Females in the study had more joint laxity than males at any age. Loudon, Goist, and Loudon[41] operationally defined knee hyperextension (genu recurvatum) as more than 5 degrees of extension beyond the 0 position. Clinically, the authors had observed that not only was hyperextension more common in females than in males, but also that the condition might be associated with functional deficits in muscle strength, instability, and poor proprioceptive control of terminal knee extension. The authors cautioned that the female athlete with hyperextended knees may be at risk for anterior cruciate ligament injury. Hall and colleagues[42] found that 10 female patients diagnosed with hypermobility syndrome had alterations in proprioceptive acuity at the knee compared with an age-matched and gender-matched control group.

Almquist and colleagues[5] measured knee rotation in 60 healthy women and 60 healthy male volunteers aged 15 to older than 60 years. Measurements of total knee rotation were taken in both knees at 90, 60, and 30 degrees of knee flexion using applied torques of 6 and 9 Nm (newton meters). No significant differences were found in the total internal–external ROM between the right and left knees at any age or gender. However, the women in the study showed a significantly larger knee rotation ROM than the men at all tested degrees of knee flexion and at all applied torques. The women had a 10% to 20% larger range of total knee rotation than did the men.

James and Parker[43] studied knee flexion ROM in 80 men and women who ranged in age from 70 years to older than 85 years. Women had greater ROM in both active and passive knee flexion than men. Overall, knee flexion values were lower than expected for both genders, possibly owing to the fact that subjects were measured in the prone position, where the two-joint rectus femoris muscle may have limited the ROM.

In contrast to the findings of James and Parker,[43] Escalante and coworkers[38] found that female subjects had reduced passive knee flexion ROM compared with males of the same age. However, the women had on average only 2 degrees less knee flexion than did the men. The women also had a higher body mass index than did the men, which may have contributed to their reduced knee flexion.

Schwarze and Denton[25] observed no differences owing to gender in a study of 527 girls and 473 boys aged 1 to 3 days. However, it is possible that at this early stage of development gender differences had not yet had time to become manifest. Conversely, Cleffken and colleagues[44] also found no gender differences in active and passive knee flexion and extension ROM in 23 male and 19 female healthy volunteers aged 19 to 27 years.