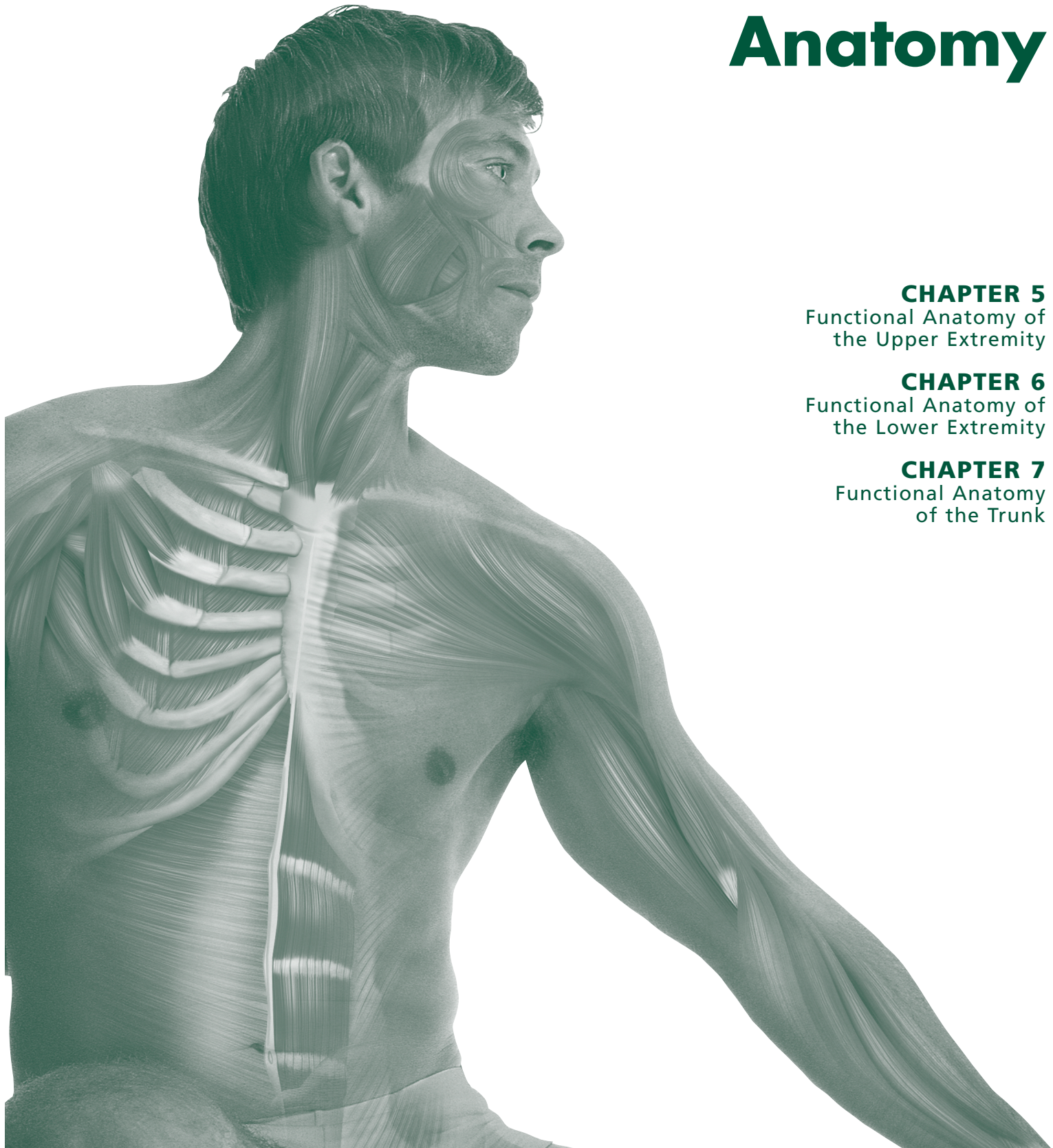


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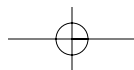
Functional Anatomy

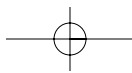
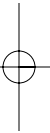
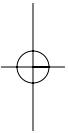
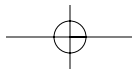


CHAPTER 5
Functional Anatomy of
the Upper Extremity

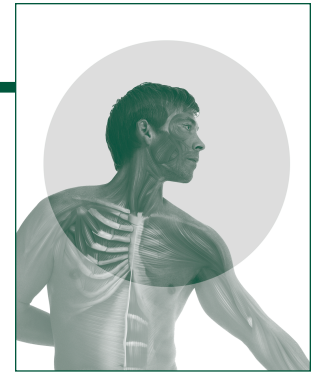
CHAPTER 6
Functional Anatomy of
the Lower Extremity

CHAPTER 7
Functional Anatomy
of the Trunk





CHAPTER 5



Functional Anatomy of the Upper Extremity

OBJECTIVES

After reading this chapter, the student will be able to:

1. Describe the structure, support, and movements of the joints of the shoulder girdle, shoulder joint, elbow, wrist, and hand.
2. Describe the scapulohumeral rhythm in an arm movement.
3. Identify the muscular actions contributing to shoulder girdle, elbow, wrist, and hand movements.
4. Explain the differences in muscle strength across the different arm movements.
5. Identify common injuries to the shoulder, elbow, wrist, and hand.
6. Develop a set of strength and flexibility exercises for the upper extremity.
7. Identify the upper extremity muscular contributions to activities of daily living (e.g., rising from a chair), throwing, swimming, and swinging a golf club).
8. Describe some common wrist and hand positions used in precision or power.

The Shoulder Complex

Anatomical and Functional Characteristics of the Joints of the Shoulder
 Combined Movement Characteristics of the Shoulder Complex
 Muscular Actions
 Strength of the Shoulder Muscles
 Conditioning
 Injury Potential of the Shoulder Complex

The Elbow and Radioulnar Joints

Anatomical and Functional Characteristics of the Joints of the Elbow
 Muscular Actions
 Strength of the Forearm Muscles
 Conditioning
 Injury Potential of the Forearm

The Wrist and Fingers

Anatomical and Functional Characteristics of the Joints of the Wrist and Hand
 Combined Movements of the Wrist and Hand
 Muscular Actions
 Strength of the Hand and Fingers
 Conditioning
 Injury Potential of the Hand and Fingers

Contribution of Upper Extremity Musculature to Sports Skills or Movements

Overhand Throwing
 The Golf Swing

External Forces and Moments Acting at Joints in the Upper Extremity

Summary

Review Questions

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The upper extremity is interesting from a functional anatomy perspective because of the interplay among the various joints and segments necessary for smooth, efficient movement. Movements of the hand are made more effective through proper hand positioning by the elbow, shoulder joint, and shoulder girdle. Also, forearm movements occur in concert with both hand and shoulder movements (47). These movements would not be half as effective if the movements occurred in isolation. Because of our heavy use of our arms and hands, the shoulder needs a high degree of structural protection and a high degree of functional control (4).



The Shoulder Complex

The shoulder complex has many articulations, each contributing to the movement of the arm through coordinated joint actions. Movement at the shoulder joint involves a complex integration of static and dynamic stabilizers. There must be free motion and coordinated actions between all four joints: the **scapulothoracic**, **sternoclavicular**, **acromioclavicular**, and **glenohumeral joints** (63,75). Although it is possible to create a small amount of movement at any one of these articulations in isolation, movement usually is generated at all of these joints concomitantly as the arm is raised or lowered or if any other significant arm action is produced (88).

ANATOMICAL AND FUNCTIONAL CHARACTERISTICS OF THE JOINTS OF THE SHOULDER

Sternoclavicular Joint

The only point of skeletal attachment of the upper extremity to the trunk occurs at the sternoclavicular joint. At this joint, the **clavicle** is joined to the manubrium of the sternum. The clavicle serves four roles by serving as a site of muscular attachment, providing a barrier to protect underlying structures, acting as a strut to stabilize the shoulder and prevent medial displacement when the muscles contract, and preventing an inferior migration of the shoulder girdle (75). The large end of clavicle articulating with a small surface on the sternum at the sternoclavicular joint requires significant stability from the ligaments (75). A close view of the clavicle and the sternoclavicular joint is shown in Figure 5-1. This gliding synovial joint has a fibrocartilaginous disc (89). The joint is reinforced by three ligaments: the interclavicular, costoclavicular, and sternoclavicular ligaments, of which the costoclavicular ligament is the main support for the joint (73) (Fig. 5-2). The joint is also reinforced and supported by muscles, such as the short, powerful subclavius. Additionally, a strong joint capsule contributes to making the joint resilient to **dislocation** or disruption.

Movements of the clavicle at the sternoclavicular joint occur in three directions, giving it three degrees of

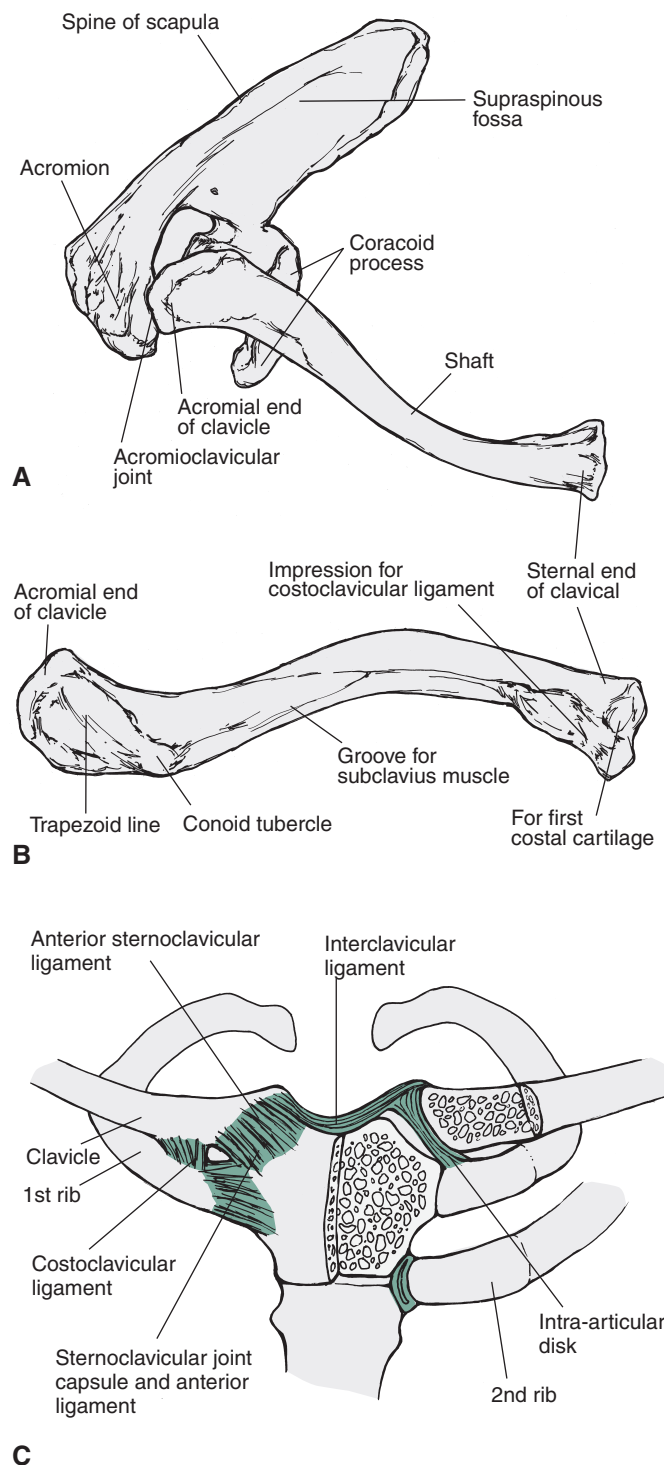
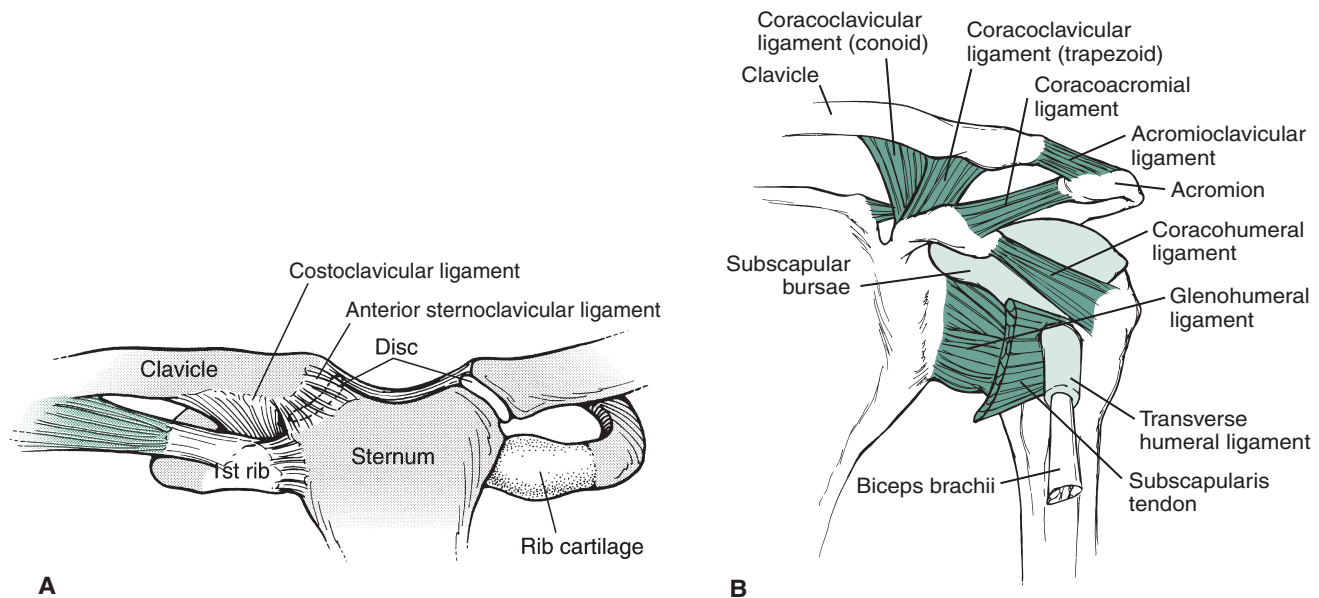


FIGURE 5-1 The clavicle articulates with the acromion process on the scapula to form the acromioclavicular joint (A). An S-shaped bone (B), the clavicle also articulates with the sternum to form the sternoclavicular joint (C).

freedom. The clavicle can move superiorly and inferiorly in movements referred to as **elevation** and **depression**, respectively. These movements take place between the clavicle and the meniscus in the sternoclavicular joint and have a range of motion of approximately 30° to 40° (75,89).



Ligament	Insertion	Action
Acromioclavicular	Acromion process TO clavicle	Prevents separation of clavicle and scapula; prevents posterior and anterior displacement
Coracoacromial	Coracoid process TO acromion process	Forms arch over shoulder
Coracoclavicular: Trapezoid, conoid	Base of coracoid process TO inferior surface of clavicle	Maintains relationship between scapula and clavicle; prevents anterior and posterior scapula movements; prevents upward and downward movements of clavicle on scapula
Coracohumeral	Base of lateral coracoid process TO greater and lesser tuberosity on humerus	Checks upward displacement of humeral head; checks external rotation; prevents posterior glide of humeral head during flexion, adduction, and internal rotation; prevents inferior translation of humeral head during shoulder adduction
Costoclavicular	Upper surface of first rib to inferior clavicle	Anterior fibers resist excessive upper rotation, and posterior fibers resist excessive downward rotation of clavicle; checks clavicle elevation and anterior, posterior, lateral movement
Glenohumeral: Inferior, middle, superior	Upper anterior edge of glenoid TO over, in front of, below humeral head	Taut in external rotation and abduction; limits anterior translation of humerus
Interclavicular	Superomedial clavicle TO capsule and upper sternum	Prevents superior and lateral displacement of clavicle on sternum; checks against excessive downward rotation of clavicle
Sternoclavicular: anterior, posterior	Clavicle TO sternum	Prevents anterior and posterior glide of clavicle
Transverse	Across bicipital groove	Keeps biceps tendon in groove

FIGURE 5-2 Ligaments of the shoulder region. Anterior aspects of the sternum (A) and shoulder (B) are shown.

The clavicle can also move anteriorly and posteriorly via movements in the transverse plane termed **protraction** and **retraction**, respectively. These movements occur between the sternum and the meniscus in the joint through a range of motion of approximately 30° to 35° in each direction (75). Finally, the clavicle can rotate anteriorly and posteriorly along its long axis through approximately 40° to 50° (75,89).

Acromioclavicular Joint

The clavicle is connected to the scapula at its distal end via the acromioclavicular (AC) joint (Fig. 5-1). This is a small, gliding synovial joint that is the size of 9 by 19 mm in adults (75) and it frequently has a fibrocartilaginous disc

similar to the sternoclavicular joint (73). At this joint, most of the movements of the scapula on the clavicle occur, and the joint handles large contact stresses as a result of high axial loads that are transmitted through the joint (75).

The AC joint lies over the top of the humeral head and can serve as a bony restriction to arm movements above the head. The joint is reinforced with a dense capsule and a set of **AC** ligaments lying above and below the joint (Fig. 5-2). The AC ligaments primarily support the joint in low load and small movement situations. Close to the AC joint is the important **coracoclavicular** ligament, which assists scapular movements by serving as an axis of rotation and by providing substantial support in

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movements requiring more range of motion and displacement. The shoulder girdle is suspended from the clavicle by this ligament and serves as the primary restraint to vertical displacement (75).

Another ligament in the region that does not cross a joint is the **coracoacromial** ligament. This ligament protects underlying structures in the shoulder and can limit excessive superior movement of the humeral head.

Scapulothoracic Joint

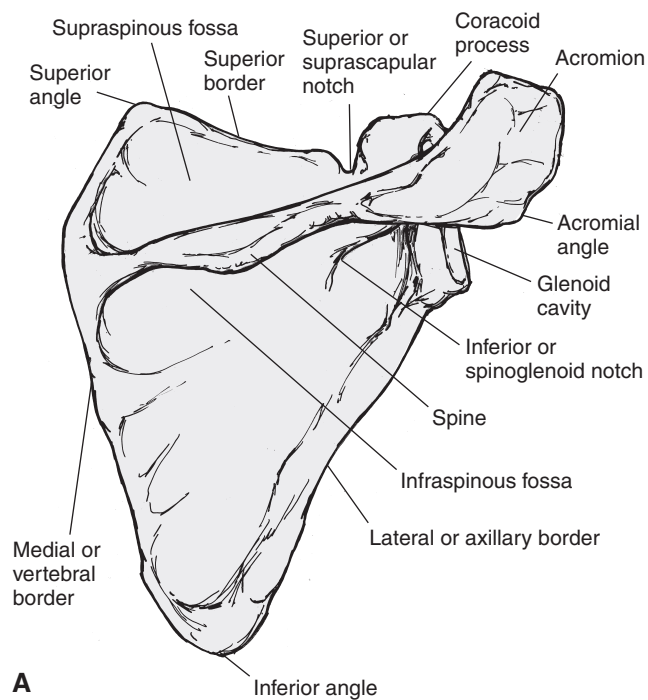
The scapula interfaces with the thorax via the **scapulothoracic joint**. This is not a typical articulation, connecting bone to bone. Rather, it is a physiological joint (89) containing neurovascular, muscular, and bursal structures that allow for a smooth motion of the scapula on the thorax (75). The scapula actually rests on two muscles, the serratus anterior and the subscapularis, both connected to the scapula and moving across each other as the scapula moves. Underneath these two muscles lies the thorax.

Seventeen muscles attach to or originate on the scapula (75). As shown in Figure 5-3, the scapula is a large, flat, triangular bone with five thick ridges (glenoid, spine, medial and lateral border, coracoid process) and two thin, hard, laminated surfaces (infraspinous and supraspinous fossas) (27). It serves two major functions relative to shoulder motion. First, the scapulothoracic articulation offers another joint so that the total rotation of the humerus with respect to the thorax increases (27). This increases the range of motion beyond the 120° generated solely in the glenohumeral joint. As the arm elevates at the glenohumeral joint, there is one degree of scapulothoracic elevation for every two degrees of glenohumeral elevation (75).

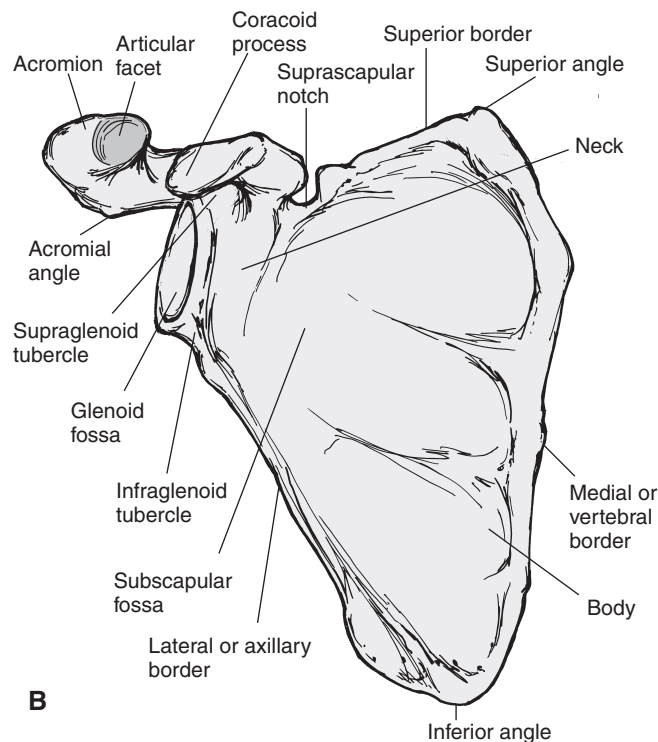
The second function of the scapula is facilitating a large lever for the muscles attaching to the scapula. Because of its size and shape, the scapula provides large movements around the AC and the sternoclavicular joints. Small muscles in the region can provide a sufficient amount of torque to be effective at the shoulder joint (27).

The scapula moves across the thorax as a consequence of actions at the AC and the sternoclavicular joints, giving a total range of motion for the scapulothoracic articulation of approximately 60° of motion for 180° of arm abduction or flexion. Approximately 65% of this range of motion occurs at the sternoclavicular joint, and 35% occurs as a result of AC joint motion (89). The clavicle acts as a crank for the scapula, elevating and rotating to elevate the scapula.

The movement of the scapula can occur in three directions, as shown in Figure 5-4. The scapula can move anteriorly and posteriorly about a vertical axis; these motions are known as **protraction** or **abduction** and **retraction** or **adduction**, respectively. Protraction and retraction occur as the acromion process moves on the meniscus in the joint and as the scapula rotates about the medial coracoclavicular ligament. There can be anywhere from 30° to 50° of protraction and retraction of the scapula (73).



A



B

FIGURE 5-3 The scapula is a flat bone that serves as a site of muscular attachment for many muscles. The dorsal (A) and ventral (B) surface of the scapula on the right side are shown.

The second scapular movement occurs when the base of the scapula swings laterally and medially in the frontal plane. These actions are termed *upward* and *downward rotation*. This movement occurs as the clavicle moves on the meniscus in the joint and as the scapula rotates about

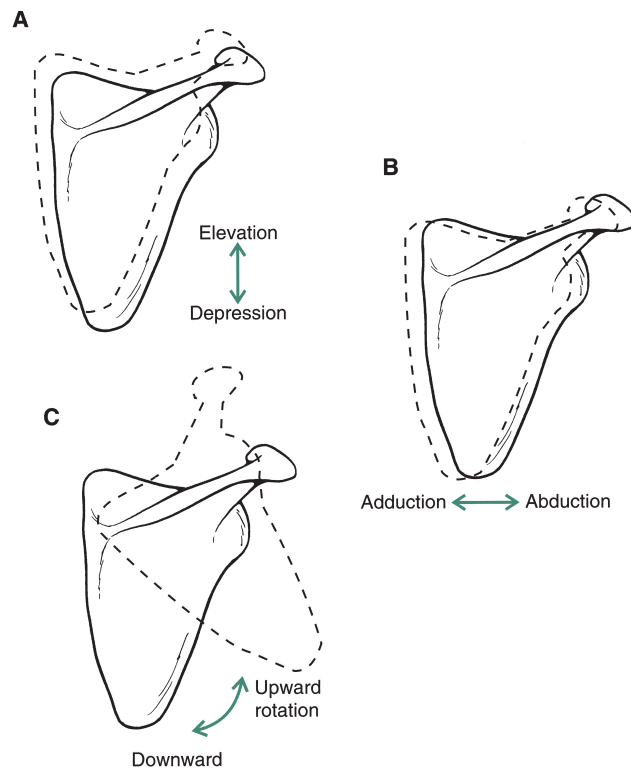
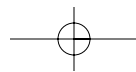


FIGURE 5-4 Scapular movements take place in three directions. **A.** Elevation and depression of the scapula occur with a shoulder shrug or when the arm raises. **B.** Abduction (protraction) and adduction (retraction) occur when the scapulae are drawn away from or toward the vertebrae, respectively, or when the arm is brought in front or behind the body, respectively. **C.** The scapula also rotates upward and downward as the arm raises and lowers, respectively.

the trapezoid portion of the lateral coracoclavicular ligament. This movement can occur through a range of motion of approximately 60° (89).

The third and final movement potential, or degree of freedom, is the scapular movement up and down, termed *elevation* and *depression*. This movement occurs at the AC joint and is not assisted by rotations about the coracoclavicular ligament. The range of motion at the AC joint for elevation and depression is approximately 30° (73,89).

The scapula movements also depend on the movement and position of the clavicle. The movements at the sternoclavicular joint are opposite to the movements at the AC joint for elevation, depression, protraction, and retraction. For example, as elevation occurs at the AC joint, depression occurs at the sternoclavicular joint and vice versa. This is not true for rotation because the clavicle rotates in the same direction along its length. The clavicle does rotate in different directions to accommodate the movements of the scapula: anteriorly with protraction and elevation and posteriorly with retraction and depression.

Glenohumeral Joint

The final articulation in the shoulder complex is the shoulder joint, or the glenohumeral joint, illustrated in Figure 5-5. Motions at the shoulder joint are represented by the

movements of the arm. This is a synovial ball-and-socket joint that offers the greatest range of motion and movement potential of any joint in the body.

The joint contains a small, shallow socket called the **glenoid fossa**. This socket is only one quarter the size of the humeral head that must fit into it. One of the reasons the shoulder joint is suited for extreme mobility is because of the size difference between the humeral head and the small glenoid fossa on the scapula (4). At any given time, only 25% to 30% of the humeral head is in contact with the glenoid fossa, but this does not necessarily lead to excessive movement because in the normal shoulder, the head of the humerus is constrained to within 1 to 2 mm of the center of the glenoid cavity by muscles (75).

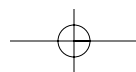
Shoulder Joint Stability Because there is minimal contact between the glenoid fossa and the head of the humerus, the shoulder joint largely depends on the ligamentous and muscular structures for stability. Stability is provided by both static and dynamic components, which provide restraint and guide and maintain the head of the humerus in the glenoid fossa (4,75).

The passive, static stabilizers include the articular surface, glenoid labrum, joint capsule, and ligaments (15,75). The articular surface of the glenoid fossa is slightly flattened and has thicker articular cartilage at the periphery, creating a surface for interface with the humeral head. The joint is also fully sealed, which provides suction and resists a dislocating force at low loads (75).

The joint cavity is deepened by a rim of fibrocartilage referred to as the **glenoid labrum**. This structure receives supplementary reinforcement from the surrounding ligaments and tendons. The labrum varies from individual to individual and is even absent in some cases (68). The glenoid labrum increases the contact area to 75% and deepens the concavity of the joint by 5 to 9 mm (75).

The joint capsule has approximately twice the volume of the humeral head, allowing the arm to be raised through a considerable range of motion (29). The capsule tightens in various extreme positions and is loose in the midrange of motion (75). For example, the inferior capsule tightens in extreme abduction and external rotation seen in throwing (32). Likewise, the anterosuperior capsule works with the muscles to limit inferior and posterior translation of the humeral head and the posterior capsule limits posterior humeral translation when the arm is flexed and internally rotated (15).

The final set of passive stabilizers consists of the ligaments (Fig. 5-2). The **coracohumeral** ligament is taut when the arm is adducted, and it constrains the humeral head on the glenoid in this position (75) by restraining inferior translation. It also prevents posterior translation of the humerus during arm movements and supports the weight of the arm. The three **glenohumeral** ligaments reinforce the capsule, prevent anterior displacement of the humeral head, and tighten up when the shoulder externally rotates.



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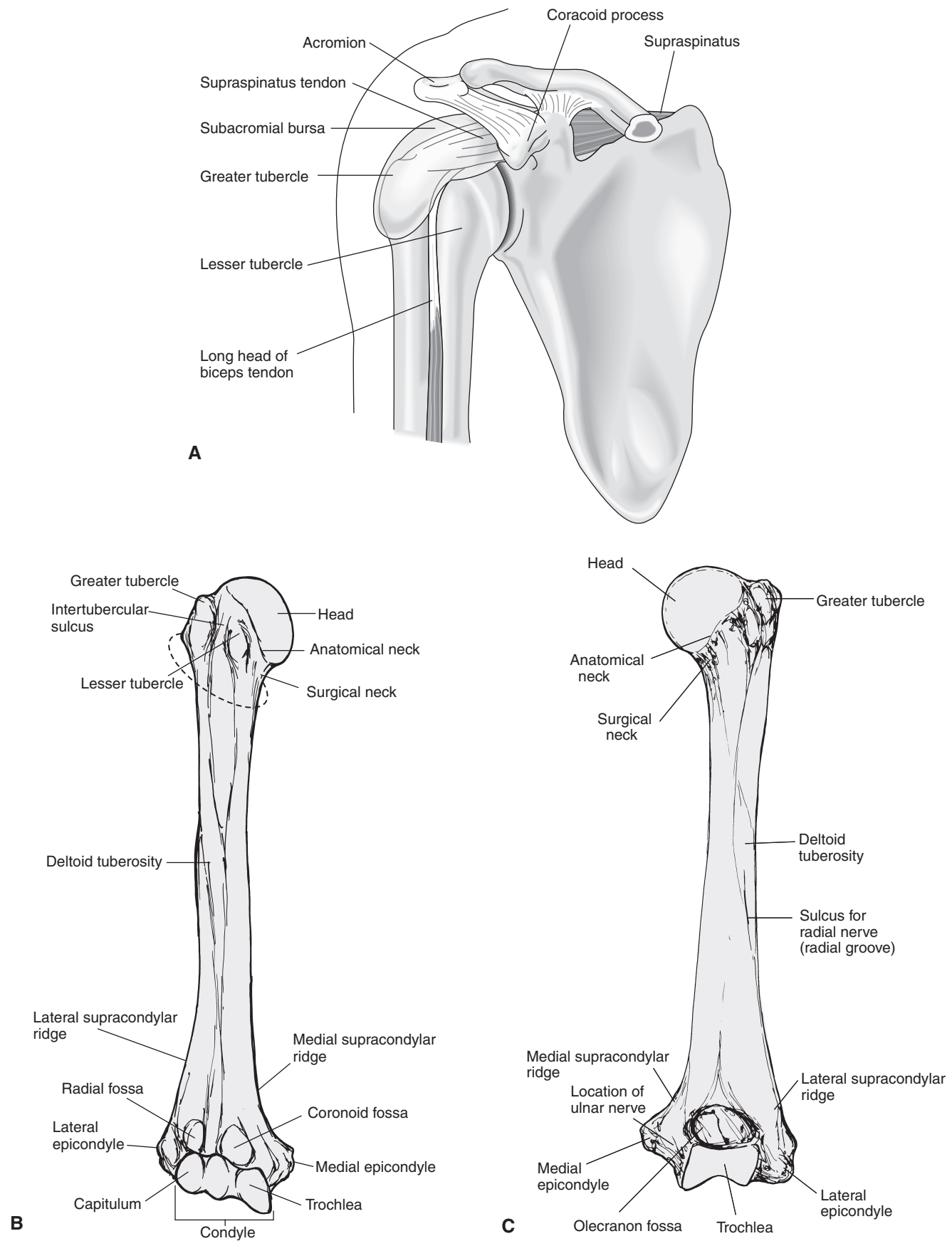


FIGURE 5-5 The head of the humerus articulates with the glenoid fossa on the scapula to form the glenohumeral joint. The landmarks of the shoulder complex (A) and the anterior (B) and posterior (C) surfaces of the humerus are shown.

Dynamic support of the shoulder joint occurs primarily in the midrange of motion and is provided by the muscles as they contract in a coordinated pattern to compress the humeral head in the glenoid cavity (15). The posterior rotator cuff muscles provide significant posterior stability, the subscapularis muscle provides anterior stability, the long head of the biceps brachii prevents anterior and superior humeral head translation, and the deltoid and the other scapulothoracic muscles position the scapula to provide maximum glenohumeral stability (15). When all of the rotator cuff muscles contract, the humeral head is compressed into the joint, and with an asymmetric contraction of the rotator cuff, the humeral head is steered to the correct position (75). This muscle group also rotates and depresses the humeral head during arm elevation to keep the humeral head in position. These muscles are examined more closely in a later section.

On the anterior side of the joint, support is provided by the capsule, the glenoid labrum, the glenohumeral ligaments, three reinforcements in the capsule, the coracohumeral ligament, fibers of the subscapularis, and the pectoralis major (78). These muscles blend into the joint capsule (29). Both the coracohumeral and the middle glenohumeral ligament support and hold up the relaxed arm. They also offer functional support through abduction, external rotation, and extension (43,73). Posteriorly, the joint is reinforced by the capsule, the glenoid labrum, and fibers from the teres minor and infraspinatus, which also blend into the capsule.

The superior aspect of the shoulder joint is often termed the *impingement area*. The glenoid labrum, the coracohumeral ligament, and the muscles support the superior portion of the shoulder joint, and the supraspinatus and the long head of the biceps brachii reinforce the capsule. Above the supraspinatus muscle lie the **subacromial bursae** and the coracoacromial ligament. These form an arch underneath the AC joint. This area and a typical impingement position are presented in Figure 5-6.

A **bursa** is a fluid-filled sac found at strategic sites around the synovial joints that reduces the friction in the

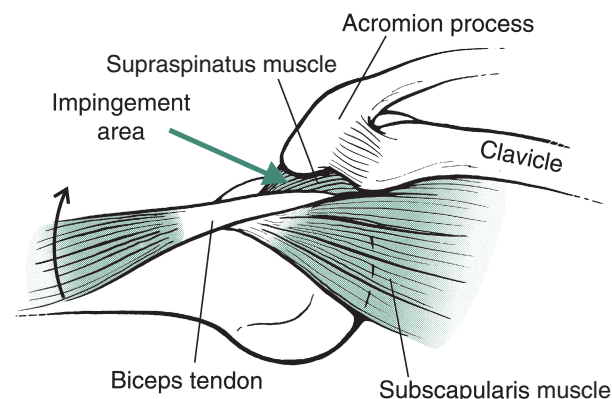


FIGURE 5-6 The impingement area of the shoulder contains structures that can be damaged with repeated overuse. The actual impingement occurs in the abducted position with the arm rotated.

joint. The supraspinatus muscle and the bursae in this area are compressed as the arm rises above the head and can be irritated if the compression is of sufficient magnitude or duration. The inferior portion of the shoulder joint is minimally reinforced by the capsule and the long head of the triceps brachii.

Movement Characteristics

The range of motion at the shoulder joint is considerable for the aforementioned structural reasons (Fig. 5-7). The arm can move through approximately 165° to 180° of flexion to approximately 30° to 60° of hyperextension in the sagittal plane (11,89). The amount of flexion can be limited if the shoulder joint is also externally rotated. With the joint in maximal external rotation, the arm can be flexed through only 30° (11). Also, during passive flexion and extension, there is accompanying anterior and posterior translation, respectively, of the head of the humerus on the glenoid (30).

The arm can also abduct through 150° to 180° . The abduction movement can be limited by the amount of internal rotation occurring simultaneously with abduction. If the joint is maximally rotated internally, the arm

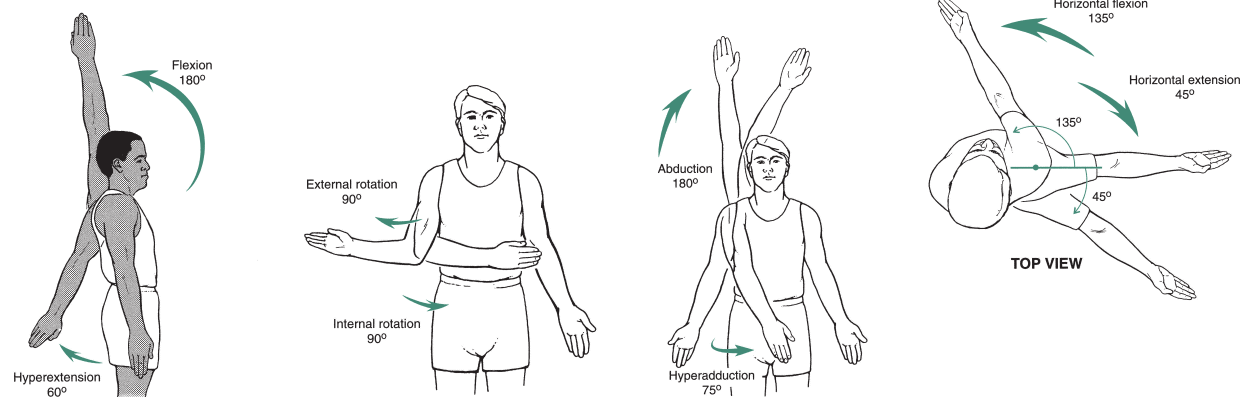


FIGURE 5-7 The shoulder has considerable range of motion. The arm can move through 180° of flexion or abduction, 60° of hyperextension, 75° of hyperadduction, 90° of internal and external rotation, 135° of horizontal flexion, and 45° of horizontal extension.

Necessary range of motion at the shoulder and elbow

Activity	Shoulder Range of Motion	Elbow Range of Motion
Combing hair	20° to 100° of elevation with 37.7° of rotation	115° of flexion
Eating with a spoon	36°	116° of flexion with 33° of pronation
Reading	57.5° of elevation with 5° of rotation	20° of flexion with 102° of pronation

Magermans, D. J., et al. (2005). Requirements for upper extremity motions during activities of daily living. *Clinical Biomechanics*, 20:591–599.

can produce only about 60° of abduction (11), but a certain amount of rotation is needed to reach 180°. As the arm adducts down to the anatomical or neutral position, it can continue past the neutral position for approximately 75° of hyperadduction across the body.

The arm can rotate both internally and externally 60° to 90° for a total of 120° to 180° of rotation (29). Rotation is limited by abduction of the arm. In an anatomical position, the arm can rotate through the full 180°, but in 90° of abduction, the arm can rotate only through 90° (11). Finally, the arm can move across the body in an elevated position for 135° of **horizontal flexion** or adduction and 45° of **horizontal extension** or abduction (89).

COMBINED MOVEMENT CHARACTERISTICS OF THE SHOULDER COMPLEX

The movement potential of each joint was examined in the previous section. This section examines the movement of the shoulder complex as a whole, sometimes referred to as **scapulohumeral rhythm**.

As stated earlier, the four joints of the shoulder complex must work together in a coordinated action to create arm movements. Any time the arm is raised in flexion or abduction, accompanying scapular and clavicular movements take place. The scapula must rotate upward to allow full flexion and abduction at the shoulder joint, and the clavicle must elevate and rotate upward to allow the scapular motion. A posterior view of the relationship between the arm and scapular movements is shown in Figure 5-8.

In the first 30° of abduction or the first 45° to 60° of flexion, the scapula moves either toward the vertebral

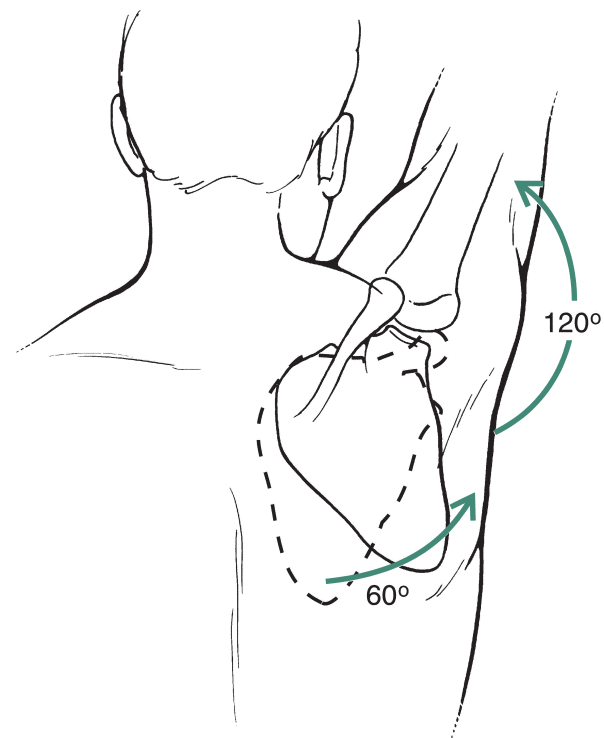
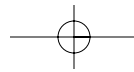


FIGURE 5-8 The movement of the arm is accompanied by movements of the shoulder girdle. The working relationship between the two is known as the scapulohumeral rhythm. The arm can move through only 30° of abduction and 45° to 60° of flexion with minimal scapular movements. Past these points, the scapula movements occur concomitantly with the arm movements. For 180° of flexion or abduction, approximately 120° of motion occurs in the glenohumeral joint and 60° of motion occurs as a result of scapular movement on the thorax.

column or away from the vertebral column to seek a position of stability on the thorax (73). After stabilization has been achieved, the scapula moves laterally, anteriorly, and superiorly in the movements described as upward rotation, protraction or abduction, and elevation. The clavicle also rotates posteriorly, elevates, and protracts as the arm moves through flexion or abduction (20).

In the early stages of abduction or flexion, the movements are primarily at the glenohumeral joint except for the stabilizing motions of the scapula. Past 30° of abduction or 45° to 60° of flexion, the ratio of glenohumeral to scapular movements becomes 5:4. That is, there is 5° of humeral movement for every 4° of scapular movement on the thorax (67,73). For the total range of motion through 180° of abduction or flexion, the glenohumeral to scapula ratio is 2:1; thus, the 180° range of motion is produced by 120° of glenohumeral motion and 60° of scapular motion (29). The contributing joint actions to the scapular motion are 20° produced at the AC joint, 40° produced at the sternoclavicular joint, and 40° of posterior clavicular rotation (20).

As the arm abducts to 90°, the greater tuberosity on the humeral head approaches the coracoacromial arch, compression of the soft tissue begins to limit further abduction, and the tuberosity makes contact with the



acromion process (20). If the arm is externally rotated, 30° more abduction can occur as the greater tuberosity is moved out from under the arch. Abduction is limited even more and can occur through only 60° with arm internal rotation because the greater tuberosity is held under the arch (20). External rotation accompanies abduction up through about 160° of motion. Also, full abduction cannot be achieved without some extension of the upper trunk to assist the movement.

MUSCULAR ACTIONS

The insertion, action, and nerve supply for each individual muscle of the shoulder joint and shoulder girdle are outlined in Figure 5-9. Most muscles in the shoulder region stabilize as well as execute movements. Special interactions between the muscles are presented in this section.

The muscles contributing to shoulder abduction and flexion are similar. The deltoid generates about 50% of the

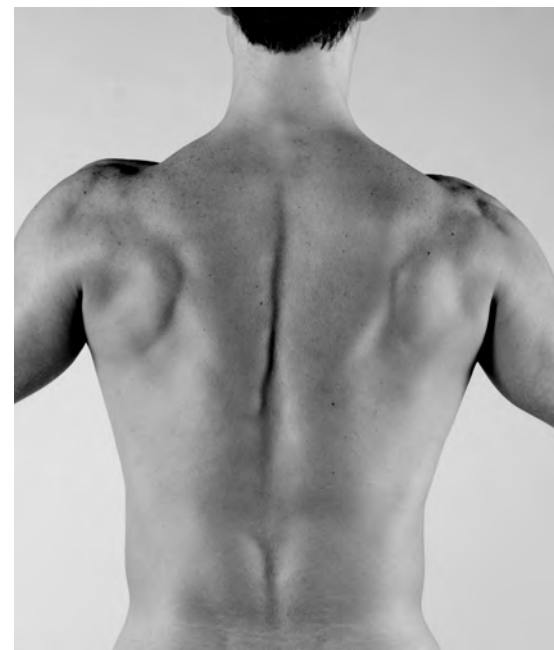
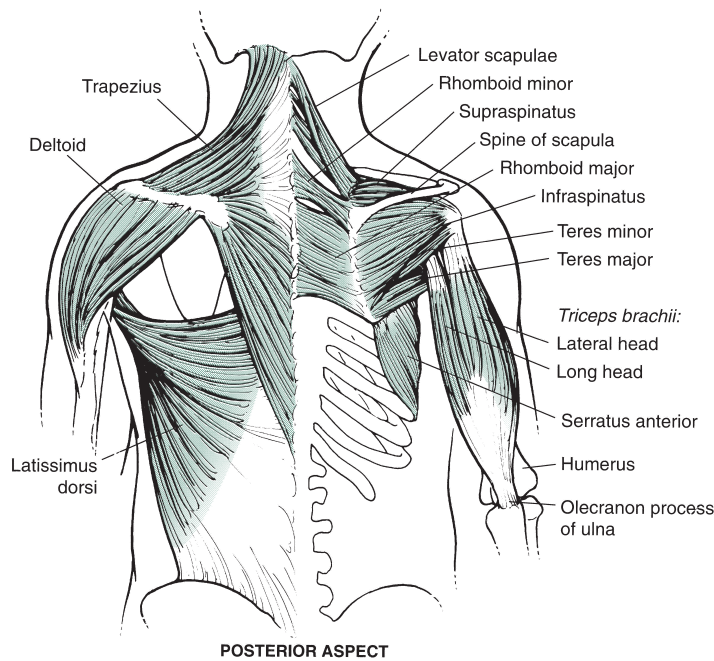
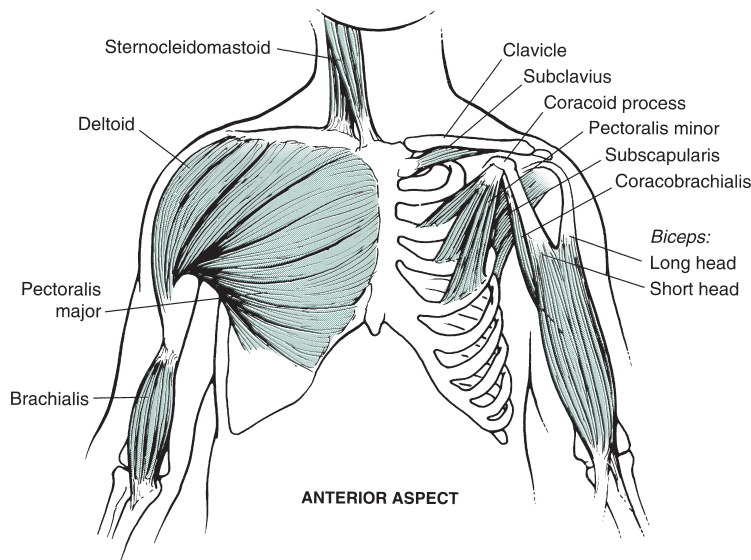
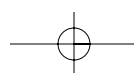
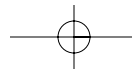


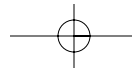
FIGURE 5-9 Muscles acting on the shoulder joint and shoulder girdle, anterior (*top*) and posterior (*bottom*) aspects. Along with insertion and nerve supply, the muscles responsible for the noted movements (PM) and the assisting muscles (Asst) are included in the table on the next page.





Muscle	Insertion	Nerve Supply	Shoulder Flexion or Scapula elevation	Shoulder Extension or Scapula Depression	Shoulder Abduction or Scapula Abduction	Shoulder Adduction or Scapula Adduction	Shoulder Medial Rotation or Scapula Upward Rotation	Shoulder Lateral Rotation or Scapula Downward Rotation	Shoulder Horizontal Abduction	Shoulder Horizontal Adduction
Biceps brachii	Supraglenoid tubercle; coracoid process TO radial tuberosity	Musculocutaneous nerve; C5, C6	Asst: Shoulder							
Coracobrachialis	Coracoid process of scapula TO medial surface adjacent to deltoid tuberosity	Musculocutaneous nerve; C5, C6, C7	PM: Shoulder			Asst: Shoulder				
Deltoid	Lateral third of clavicle; acromion process; spine of scapula TO deltoid tuberosity on humerus	Axillary nerve; C5, C6	PM: Shoulder (ant and middle deltoid only)	PM: Shoulder (post deltoid only)	PM: shoulder (all three)	Asst: Shoulder	PM: Shoulder (ant deltoid only)	PM: Shoulder (post deltoid only)	PM: Shoulder (post deltoid only)	PM: Shoulder (ant deltoid only)
Infraspinatus	Infraspinous fossa TO greater tubercle on humerus	Subscapular nerve; C5, C6								
Latissimus dorsi	Spinous process of thoracic vertebrae 6–12, L1–L5; lower 3–4 ribs; iliac crest; inferior angle of scapula TO intertubercular groove on humerus	Thoracodorsal nerve; C6–C8	PM: Shoulder							
Levator scapula	Transverse process of C1–C4 TO superior angle of scapula	Cervical plexus via C3, C4; dorsal scapular nerve; C5	PM: Scapula					Asst: Scapula		
Pectoralis major	Clavicle; sternum; ribs 1–6 TO greater tubercle of humerus, intertubercular groove	Medial pectoral nerve C6–C8	PM: Shoulder	PM: Shoulder (sternal portion only)		PM: Shoulder (sternal portion only)	Asst: Shoulder			PM: Shoulder
Pectoralis minor	Ribs 3–5 TO coracoid process	Medial anterior thoracic nerve; C8, T1	PM: Scapula	PM: Scapula	PM: Scapula			PM: Scapula		
Rhomboid	Spinous process of C7, T1–T5 TO medial border of scapula	Dorsal scapular nerve; C5	PM: Scapula			PM: scapula		PM: scapula		
Serratus anterior	Ribs 1–8 TO underside of scapula along medial border	Long thoracic nerve; C5–C7	PM: Scapula		PM: Scapula		PM: Scapula			
Subclavius	Costal cartilage of rib 1 TO underside of clavicle	Brachial plexus; C5, C6		Asst: Scapula						
Subscapularis	Subscapular fossa TO lesser tubercle on humerus	Subscapular nerve; C5–C7					PM: shoulder			
Supraspinatus	Supraspinous fossa of scapula TO lesser tubercle of humerus	Subscapular nerve; C5, C6		Asst: Shoulder			Asst: Shoulder			
Teres major	Posterior surface of scapula at inferior angle TO lesser tubercle of humerus	Subscapular nerve; C5, C6		Asst: Shoulder						
Teres minor	Lateral border of posterior scapula TO greater tubercle on humerus	Axillary nerve; C5, C6						PM: Shoulder		
Trapezius	Occipital bone; ligamentum nuchae; spinous process of C1–T12 TO acromion process; spine of scapula; lateral clavicle	Accessory nerve–spinal portion of 11th cranial nerve; C3, C4	PM: Scapula (upper fibers)	PM: Scapula (lower fibers)		PM: Scapula	PM: Scapula			
Triceps Brachii	Infraspinoid tubercle on scapula; mid posterior shaft of humerus; lower shaft of humerus TO olecranon process	Radial nerve; C7, C8	Asst: Shoulder (long head)	Asst: Shoulder (long head)		Asst: Shoulder (long head)				

FIGURE 5-9 (CONTINUED)



muscular force for elevation of the arm in abduction or flexion. The contribution of the deltoid increases with increased abduction. The muscle is most active from 90° to 180° (66). However, the deltoid has been shown to be most resistant to fatigue in the range of motion from 45° to 90° of abduction, making this range of motion most popular for arm-raising exercises.

When the arm elevates, the **rotator cuff** (teres minor, subscapularis, infraspinatus, supraspinatus) also plays an important role because the deltoid cannot abduct or flex the arm without stabilization of the humeral head (89). The rotator cuff as a whole is also capable of generating flexion or abduction with about 50% of the force normally generated in these movements (29).

In the early stages of arm flexion or abduction, the deltoid's line of pull is vertical, so it is assisted by the supraspinatus, which produces abduction while at the same time compressing the humeral head and resisting the superior motion of the humeral head by the deltoid. The rotator cuff muscles contract as a group to compress the humeral head and maintain its position in the glenoid fossa (65). The teres minor, infraspinatus, and subscapularis muscles stabilize the humerus in elevation by applying a downward force. The latissimus dorsi also contracts eccentrically to assist with the stabilization of the humeral head and increases in activity as the angle increases (42). The interaction between the deltoid and the rotator cuff in abduction and flexion is shown in Figure 5-10. The inferior and medial force of the rotator cuff allows the deltoid to elevate the arm.

Above 90° of flexion or abduction, the rotator cuff force decreases, leaving the shoulder joint more vulnerable to injury (29). However, one of the rotator cuff

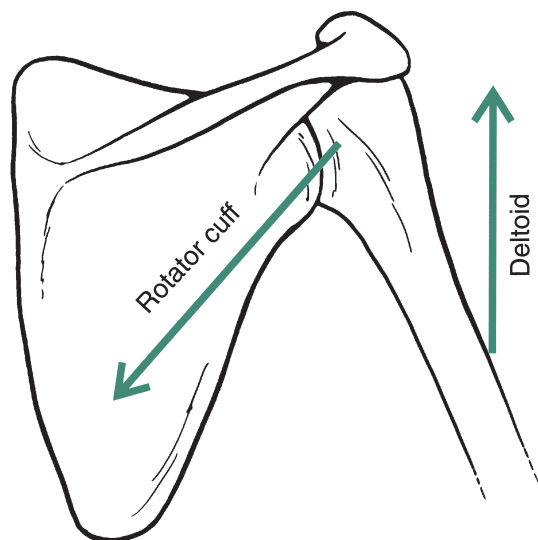


FIGURE 5-10 For efficient flexion or abduction of the arm, the deltoid muscle and the rotator cuff work together. In the early stages of abduction and flexion through 90°, the rotator cuff applies a force to the humeral head that keeps the head depressed and stabilized in the joint while the deltoid muscle applies a force to elevate the arm.

muscles, the supraspinatus, remains a major contributor above 90° of flexion or abduction. In the upper range of motion, the deltoid begins to pull the humeral head down and out of the joint cavity, thus creating a subluxating force (73). Motion through 90° to 180° of flexion or abduction requires external rotation in the joint. If the humerus externally rotates 20° or more, the biceps brachii can also abduct the arm (29).

When the arm is abducted or flexed, the shoulder girdle must protract or abduct, elevate, and upwardly rotate with posterior clavicular rotation to maintain the glenoid fossa in the optimal position. As shown in Figure 5-11, the serratus anterior and the trapezius work as a force couple to create the lateral, superior, and rotational motions of the scapula (29). These muscle actions take place after the deltoid and the teres minor have initiated the elevation of the arm and continue up through 180°, with the greatest muscular activity through 90° to 180° (66). The serratus anterior is also responsible for holding the scapula to the thorax wall and preventing any movement of the medial border of the scapula off the thorax.

If the arm is slowly lowered, producing adduction or extension of the arm with accompanying retraction, depression, and downward rotation of the shoulder girdle with forward clavicular rotation, the muscle actions are eccentric. Therefore, the movement is controlled by the muscles previously described in the arm abduction and flexion section. If the arm is forcefully lowered or if it is lowered against external resistance, such as a weight machine, the muscle action is concentric.

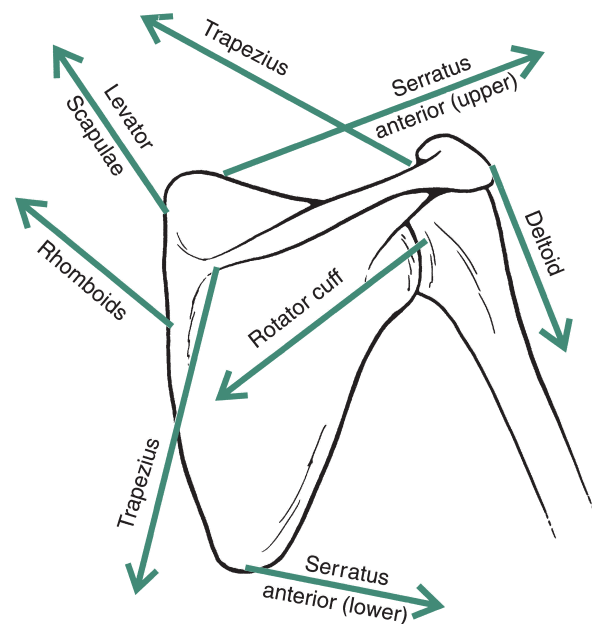


FIGURE 5-11 The direction of pull of various shoulder girdle muscles, the deltoid, and the rotator cuff for the resting arm. Note the line of pull of the trapezius and the serratus anterior, which work together to produce abduction, elevation, and upward rotation of the scapula necessary in arm flexion or abduction. Likewise, note the pull of the levator scapulae and the rhomboid, which also assist in elevation of the scapula.

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In a concentric adduction or extension against external resistance, such as in a swimming stroke, the muscles responsible for creating these joint actions are the latissimus dorsi, teres major, and sternal portion of the pectoralis major. The teres major is active only against a resistance, but the latissimus dorsi has been shown to be active in these movements even when no resistance is offered (13).

As the arm is adducted or extended, the shoulder girdle retracts, depresses, and downwardly rotates with forward clavicular rotation. The rhomboid muscle downwardly rotates the scapula and works with the teres major and the latissimus dorsi in a force couple to control the arm and scapular motions during lowering. Other muscles actively contributing to the movement of the scapula back to the resting position while working against resistance are the pectoralis minor (depresses and downwardly rotates the scapula) and the middle and lower portions of the trapezius (retract the scapula with the rhomboid). These muscular interactions are illustrated in Figure 5-12.

Two other movements of the arm, internal and external rotation, are very important in many sport skills and in the efficient movement of the arm above 90° (measured from arm at the side). An example of both external and internal rotation in a throwing action is shown in Figure 5-13. External rotation is an important component of the preparatory, or cocking, phase of an overhand throw, and internal rotation is important in the force application and follow-through phase of the throw.

External rotation, which is necessary when the arm is above 90° , is produced by the infraspinatus and the teres minor muscles (73). The activity of both of these muscles increases with external rotation in the joint (36). Because the infraspinatus is also an important muscle in humeral head stabilization, it fatigues early in elevated arm activities.

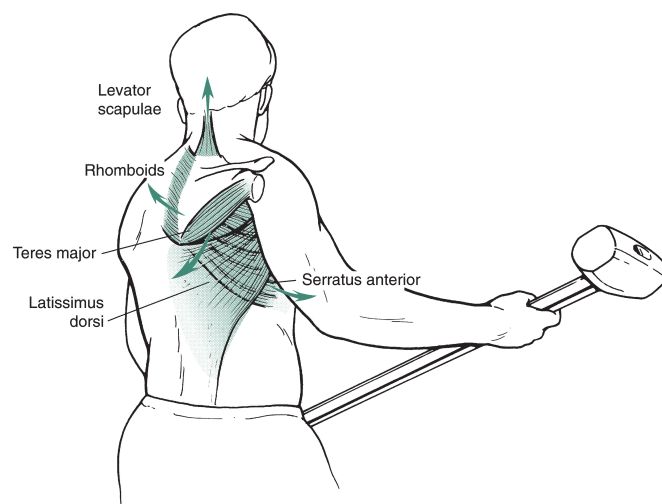


FIGURE 5-12 Lowering the arm against a resistance uses the latissimus dorsi and teres major working as a force couple with the rhomboid. Other muscles that contribute to the lowering action are the pectoralis major, pectoralis minor, levator scapulae, and serratus anterior.

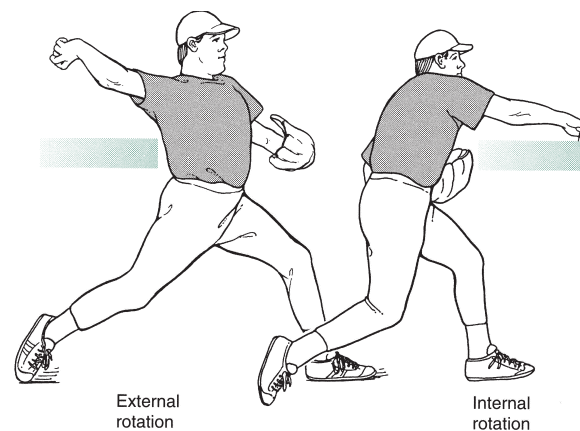


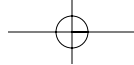
FIGURE 5-13 Shoulder joint rotation is an important contributor to the overhand throw. In the preparatory, or cocking, phase, the arm externally rotates to increase the range of motion and the distance over which the ball will travel. Internal rotation is an active contributor to the force application phase. The movement continues in the follow-through phase as the arm slows down.

Internal rotation is produced primarily by the subscapularis, latissimus dorsi, teres major, and portions of the pectoralis major. The teres major is an active contributor to internal rotation only when the movement is produced against resistance. The muscles contributing to the internal rotation joint movement are capable of generating a large force, yet the internal rotation in most upper extremity actions never requires or uses much internal rotation force (73).

The shoulder girdle movements accompanying internal and external rotation depend on the position of the arm. In an elevated arm position, the shoulder girdle movements described in conjunction with abduction and flexion are necessary. Rotation produced with the arm in the neutral or anatomical position requires minimal shoulder girdle assistance. It is also in this position that the full range of rotation through 180° can be obtained. This is because as the arm is raised, muscles used to rotate the humerus are also used to stabilize the humeral head, which is restrained in rotation in the upper range of motion. Specifically, internal rotation is difficult in elevated arm positions because the tissue under the acromion process is very compressed by the greater tuberosity (66).

Two final joint actions that are actually combinations of elevated arm positions are horizontal flexion or adduction and horizontal extension or abduction. Because the arm is elevated, the same muscles described earlier for abduction and flexion also contribute to these movements of the arm across the body.

Muscles contributing more significantly to horizontal flexion are the pectoralis major and the anterior head of the deltoid. This movement brings the arms across the body in the elevated position and is important in power movements of upper extremity skills. Horizontal extension in which the arm is brought back in the elevated position is produced primarily by the infraspinatus, teres minor, and posterior head of the deltoid. This joint action



is common in the backswing and preparatory actions in upper extremity skills (89).

STRENGTH OF THE SHOULDER MUSCLES

In a flexed position, the shoulder muscles can generate the greatest strength output in adduction when muscle fibers of the latissimus dorsi, teres major, and pectoralis major contribute to the movement. The adduction strength of the shoulder muscles is twice that for abduction, even though the abduction movement and muscle group are used more frequently in activities of daily living and sports (89).

The movement capable of generating the next greatest level of strength after the adductors is an extension movement that uses the same muscles that contribute to arm adduction. The extension action is slightly stronger than its opposite movement, flexion. After flexion, the next strongest joint action is abduction, illustrating the fact that shoulder joint actions are capable of generating greater force output in the lowering phase using the adductors and extensors than in the raising phase, when the flexors and abductors are used. These strength relationships change, however, when the shoulder is held in a neutral or slightly hyperextended position because the isometric force development is greater in the flexors than in the extensors. This reversal in strength differences is related to the length–tension relationship created by the starting point.

The weakest joint actions in the shoulder are rotational, with external rotation being weaker than internal rotation. The strength output of the rotators is influenced by arm position, and the greatest internal rotation strength can be obtained with the arm in the neutral position. The greatest external rotation strength can be obtained with the shoulder in 90° of flexion. With the arm elevated to 45°, however, both internal and external rotation strength outputs are greater in 45° of abduction than 45° of flexion (28). External rotation is important in the upper 90° of arm elevation, providing stability to the joint. Internal rotation creates instability in the joint, especially in the upper elevation levels, as it compresses the soft tissue in the joint.

Muscle strength imbalance is accentuated in athletic populations because of use patterns. For example, swimmers, water polo players, and baseball pitchers have been found to have relatively stronger adductors and internal rotators (14). In paraplegic wheelchair athletes, the adductors are relatively weaker than the abductors, and this is more pronounced in athletes with shoulder injuries (14).

CONDITIONING

The shoulder muscles are easy to stretch and strengthen because of the mobility of the joint. The muscles usually work in combination, making it difficult to isolate a specific

muscle in an exercise. Examples of stretching, manual resistance, and weight training for the shoulder abductors and flexors are presented in Figure 5-14.

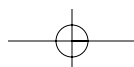
Some resistance exercises may irritate the shoulder joint and should be avoided by individuals with specific injuries. Any lateral dumbbell raise using the deltoid may cause impingement in the coracoacromial area. This impingement is magnified if the shoulder is internally rotated. A solution for those wishing to avoid impingement or who have injuries in this area is to rotate the arm externally and then perform the lateral raise (20). It is important to recognize that when an adjustment like this is made, the muscle activity and the forces generated internally also change. External rotation during a lateral raise alters the activity of the deltoid and facilitates activity in the internal rotators.

Exercises such as the bench press and push-ups should be avoided by individuals with instability in the anterior or posterior portion of the shoulder joint caused by adduction and internal rotation. Likewise, stress on the anterior portion of the capsule is produced by the pullover exercise that moves from an extreme flexed, abducted, and externally rotated position. Other exercises to be avoided by individuals with anterior capsule problems are behind-the-neck pull-downs, incline bench press, and rowing exercises. The risks in these three exercises can be minimized if no external rotation is maintained or even if some internal rotation is maintained in the joint. The external rotation position produces strain on the anterior portion of the shoulder (20). In an exercise such as the squat, which uses the lower extremity musculature, the position of the shoulder in external rotation may even prove to be harmful because of the strain on the anterior capsule created by weights held in external rotation. Attempts should be made to minimize this joint action by balancing a portion of the weight on the trapezius or using alternative exercises, such as the dead lift.

Finally, if an individual is having problems with rotator cuff musculature, heavy lifting in an abduction movement should be minimized or avoided. This is because the rotator cuff muscles must generate a large force during the abduction action to support the shoulder joint and complement the activity of the deltoid. Heavy weight lifting above the head should be avoided to reduce strain on the rotator cuff muscles (49).

INJURY POTENTIAL OF THE SHOULDER COMPLEX

The shoulder complex is subject to a wide variety of injuries that can be incurred in two ways. The first type of injury is through trauma. This type of injury usually occurs when contact is made with an external object, such as the ground or another individual. The second type of injury is through repetitive joint actions that create inflammatory sites in and around the joints or muscular attachments.



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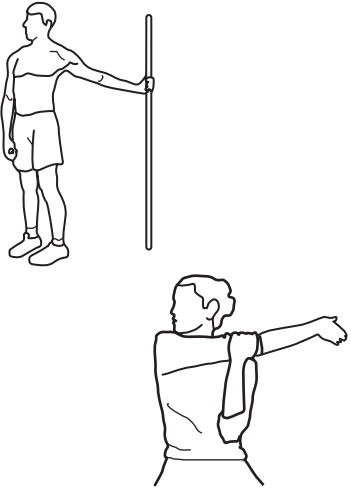
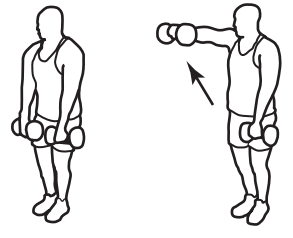
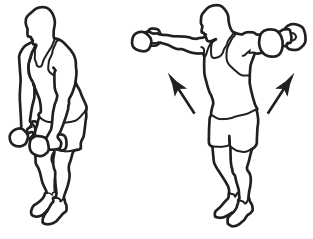
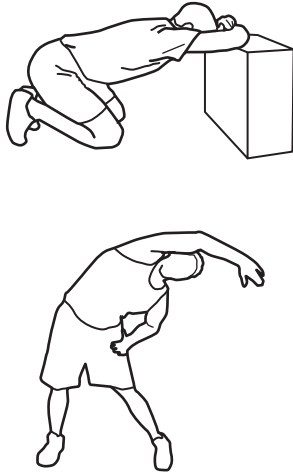
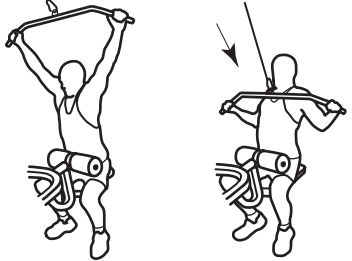
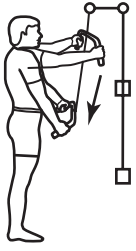
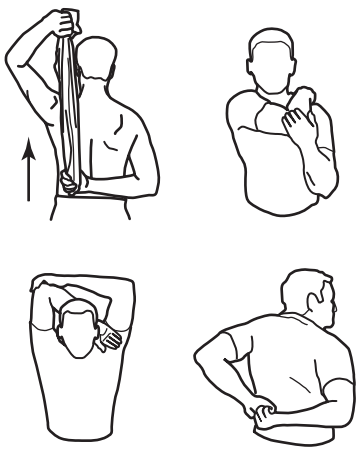
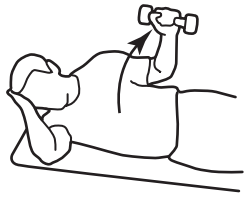
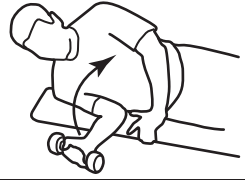
Muscle Group	Sample Stretching Exercise	Sample Strengthening Exercise	Other Exercises
Shoulder flexors/ abductors		<p>Front dumbbell raise</p>  <p>Side dumbbell raise</p> 	<p>Military press Shoulder press Upright row Front lateral raise Seated dumbbell press</p>
Shoulder extensors/ adductors		<p>Lat pull down</p>  <p>Straight arm pull down</p> 	<p>Pull up Chin up Cable pull down</p>
Shoulder rotators		<p>External rotation</p>  <p>Internal rotation</p> 	<p>Backscratch Cable external and internal rotation</p>

FIGURE 5-14 Sample stretching and strengthening exercises for selected muscle groups.

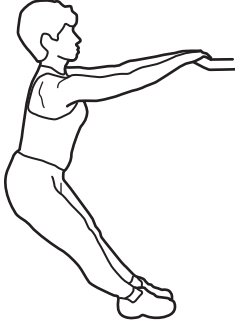
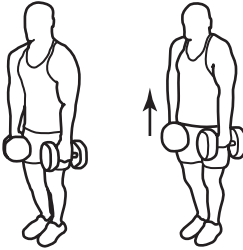
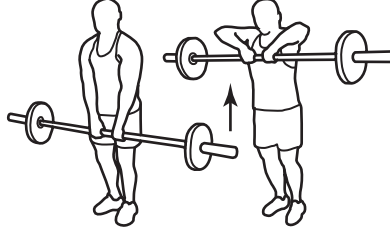

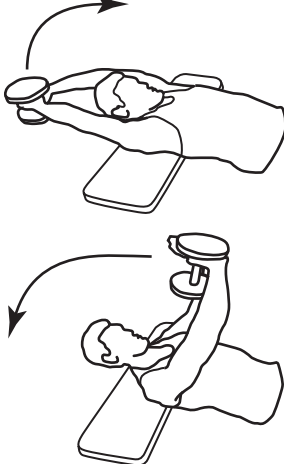
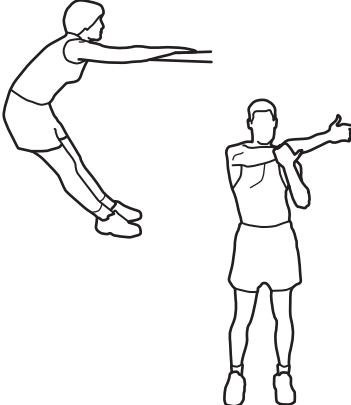
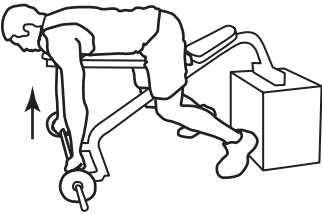
Muscle Group	Sample Stretching Exercise	Sample Strengthening Exercise	Other Exercises
Shoulder girdle elevators		<p>Dumbbell shrugs</p>  <p>Barbell upright row</p> 	<p>Barbell shrug Seated shrug Cable upright rows</p>
Shoulder girdle abductors		<p>Dumbbell pullover</p> 	<p>Push-up Standing fly Punch</p>
Shoulder girdle adductors		<p>V pull</p> 	<p>Seated rows Bent over dumbbell rows</p>

FIGURE 5-14 (CONTINUED)

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Many injuries to the shoulder girdle are traumatic, a result of impacts during falls or contact with an external object. The sternoclavicular joint can **sprain** or dislocate anteriorly if an individual falls on the top of the shoulder in the area of the middle deltoid. An individual with a sprain to this joint has pain in horizontal extension movements of the shoulder, such as in the golf swing or the backstroke in swimming (85). Anterior **subluxations** of this joint in adolescents have also occurred spontaneously during throwing because they have greater mobility in this joint than adults. A posterior dislocation or subluxation of the sternoclavicular joint can be quite serious because the trachea, esophagus, and numerous veins and arteries lie below this structure. This injury occurs as a consequence of force to the sternal end of the clavicle. The individual may have symptoms such as choking, shortness of breath, or difficulty in swallowing (85). Overall, the sternoclavicular joint is well reinforced with ligaments, and fortunately, injury in the form of sprains, subluxations, and dislocations is not common.

The clavicle is frequently a site of injury by direct trauma received through contact in football and some other sports. The most common injury is a **fracture** to the middle third of the clavicle. This injury is incurred by falling on the shoulder or outstretched arm or receiving a blow on the shoulder so that a force is applied along the shaft of the clavicle. Other less common fractures occur to the medial clavicle as a result of direct trauma to the lateral end of the clavicle or as a result of direct trauma to the tip of the shoulder (85). Clavicular fractures in adolescents heal quickly and effectively; but in adults, the healing and repair process is not as efficient or effective. This is related to the differences in the level of skeletal maturation. In adolescents, new bone is being formed at a much faster rate than in mature individuals.

Injuries to the AC joint can cause a considerable amount of disruption to shoulder movements. Again, if an individual falls on the point of the shoulder, the AC joint can subluxate or dislocate. This can also occur because of a fall on the elbow or on an outstretched arm. This joint is also frequently subjected to overuse injuries in sports using the overhand pattern, such as throwing, tennis, and swimming. Other sports that repeatedly load the joint in the overhead position, such as weight lifting and wrestling, may also cause the overuse syndrome. The consequences of overuse of the joint are capsule injury, an **ectopic calcification** in the joint, and possible **degeneration** of the cartilage (85).

The scapula rarely receives sufficient force to cause an injury. If an athlete or an individual falls on the upper back, however, it is possible to fracture the scapula and bruise the musculature so that arm abduction is quite painful. Another site of fracture on the scapula is the **coracoid process**, which can be fractured with separation of the AC joint. Throwers can also acquire **bursitis** at the inferomedial border of the scapula, causing pain as the scapula moves through the cocking and acceleration

phases in the throw. The pain is diminished in the follow-through phase. Bursitis is the inflammation of the **bursa**, a fluid-filled sac found at strategic sites around the synovial joints that reduces the friction in the joint.

Activities such as weight lifting (bench press, push-ups), lifting above the head, playing tennis, and carrying a backpack can produce trauma to the brachial nerve plexus by means of a traction force (i.e., a pulling force). If the long thoracic nerve is impinged, isolated paralysis of the serratus anterior can cause movement of the medial border of the scapula away from the thorax and a decreased ability to abduct and flex at the shoulder joint (85).

The shoulder joint is commonly injured either through direct trauma or repeated overuse. Dislocation or subluxation in the glenohumeral joint is frequent because of the lack of bony restraint and the dependence on soft tissue for restraint and support of the joint. Dislocation occurs most frequently in collision sports such as ice hockey (15). The glenoid fossa faces anterolaterally, creating more stability in the posterior joint than the anterior. Thus, the most common direction of dislocation is anterior. Anterior and inferior dislocations account for 95% of dislocations (59).

The usual cause of the dislocation is contact or some force applied to the arm when it is abducted and externally rotated overhead. This drives the humeral head anteriorly, possibly tearing the capsule or the glenoid labrum. The rate of recurrence of dislocation depends on the age of the individual and the magnitude of the force producing the dislocation (33). The recurrence rate for the general population is 33% to 50%, increasing to 66% to 90% in individuals younger than 20 years of age (66). In fact, the younger the age at the first dislocation, the more likely is a recurrent dislocation. Also, if a relatively small amount of force created the dislocation, a recurrent dislocation is more likely.

Recurrent dislocations also depend on the amount of initial damage and whether the glenoid labrum was also damaged (64). A tear to the glenoid labrum, similar to tearing the meniscus in the knee, results in clicking and pain with the arm overhead (88). An anterior dislocation also makes it difficult to rotate the arm internally, so that the contralateral shoulder cannot be touched with the hand on the injured side.

Posterior dislocations of the shoulder are rare (2%) and are usually associated with a force applied with an adducted and internally rotated arm with the hand below shoulder level (88). The clinical signs of a posterior dislocation are inability to abduct and externally rotate the arm.

Soft tissue injuries at the shoulder joint are numerous and are most often associated with overhead motions of the arm, such as in throwing, swimming, and racquet sports. Because of the extreme range of motions and high velocities in throwing, the dynamic stabilizing structures of the shoulder joint are at great risk of injury (52). Injuries in this category include examples such as posterior and anterior instability, impingement, and glenoid labrum damage. The rotator cuff muscles, which are active

in controlling the humeral head and motion during the overhand pattern, are very susceptible to injury.

In an upper extremity throwing pattern, when the arm is in the preparatory phase with the shoulder abducted and externally rotated, the anterior capsule—specifically, the subscapularis muscle—is susceptible to strain or tendinitis at the insertion on the lesser tuberosity (72). In late cocking and early acceleration phase, the posterior portion of the capsule and posterior labrum are susceptible to injury as the anterior shoulder is tightened, driving the head of the humerus backward (10). In the follow-through phase, when the arm is brought horizontally across the body at a very high speed, the posterior rotator cuff, infraspinatus, and teres minor are very susceptible to muscle strain or tendinitis on the greater tuberosity insertion site as they work to decelerate the arm (19).

The most common mechanism of injury to the rotator cuff occurs when the greater tuberosity pushes against the underside of the acromion process. This subacromial **impingement syndrome** occurs during the acceleration phase of the overhand throwing pattern when the arm is internally rotating while still maintained in the abducted position. Impingement can also occur in the lead arm of golfers and in a variety of other activities that use the overhead pattern (40). The rotator cuff, subacromial bursa, and biceps tendon are compressed against the anterior undersurface of the acromion and coracoacromial ligament (51) (Fig. 5-6). The impingement has been seen as main source of soft tissue injury, although others point to tension overload, overuse, and traumatic injury as other competing sources of injury to the rotator cuff (51). Impingement occurs in the range of 70° to 120° of flexion or abduction and is most common in such activities as the tennis serve, throwing, and the butterfly and crawl strokes in swimming (29). If an athlete maintains the shoulder joint in an internally rotated position, impingement is more likely to occur. It is also commonly injured in wheelchair athletes and in individuals transferring from a wheelchair to a bed or chair (9,14). The supraspinatus muscle, lying in the subacromial space, is compressed and can be torn with impingement, and with time, calcific deposits can be laid down in the muscle or tendon. This irritation can occur with any overhead activity, creating a painful arc of arm motion through 60° to 120° of abduction or flexion (73).

Another injury that is a consequence of impingement is **subacromial bursitis**. This injury results from an irritation of the bursae above the supraspinatus muscle and underneath the acromion process (29). It also develops in wheelchair propulsion because of greater-than-normal pressures in the joint and abnormal distribution of stress in the subacromial area (9).

Finally, the tendon of the long head of the biceps brachii can become irritated when the arm is forcefully abducted and rotated. **Bicipital tendinitis** develops as the biceps tendon is subluxated or irritated within the bicipital groove. In throwing, the arm externally rotates to 160°

in the cocking phase, and the elbow moves through 50° of motion. Because the biceps brachii acts on the shoulder and is responsible for decelerating the elbow in the final 30° of extension, it is often maximally stressed (6). In a rapid throw, the long head of the biceps brachii may also be responsible for tearing the anterosuperior portion of the glenoid labrum. Irritation to the biceps tendon is manifested in a painful arc syndrome similar to that of the rotator cuff injury.

In summary, the shoulder complex has the greatest mobility of any region in the body, but as a consequence of this great mobility, it is an unstable area in which numerous injuries may occur. Despite the high probability of injury, successful rehabilitation after surgery is quite common. It is important to maintain the strength and flexibility of the musculature surrounding the shoulder complex because there is considerable dependence on the musculature and soft tissue for support and stabilization.



The Elbow and Radioulnar Joints

The role of forearm movement, generated at the elbow or **radioulnar joint**, is to assist the shoulder in applying force and in controlling the placement of the hand in space. The combination of shoulder and elbow–radioulnar joint movements affords the capacity to place the hand in many positions, allowing tremendous versatility. Whether you are working above your head, shaking someone’s hand, writing a note, or tying your shoes, hand position is important and is generated by the working relationship between the shoulder complex and the forearm. The elbow joint also works as a fulcrum for the forearm, allowing both powerful grasping and fine hand motion (24).

ANATOMICAL AND FUNCTIONAL CHARACTERISTICS OF THE JOINTS OF THE ELBOW

The elbow is considered a stable joint, with structural integrity, good ligamentous support, and good muscular support. The elbow has three joints allowing motion between the three bones of the arm and forearm (humerus, radius, ulna). Movement between the forearm and the arm takes place at the ulnohumeral and radiohumeral articulations, and movements between the radius and the ulna take place at the radioulnar articulations (73). Landmarks on the radius and ulna and the ulnohumeral, radiohumeral, and proximal radioulnar articulations are shown in Figure 5-15.

Ulnohumeral Joint

The **ulnohumeral joint** is the articulation between the ulna and the humerus and is the major contributing joint to flexion and extension of the forearm. The joint is the union between the spool-like **trochlea** on the distal end of

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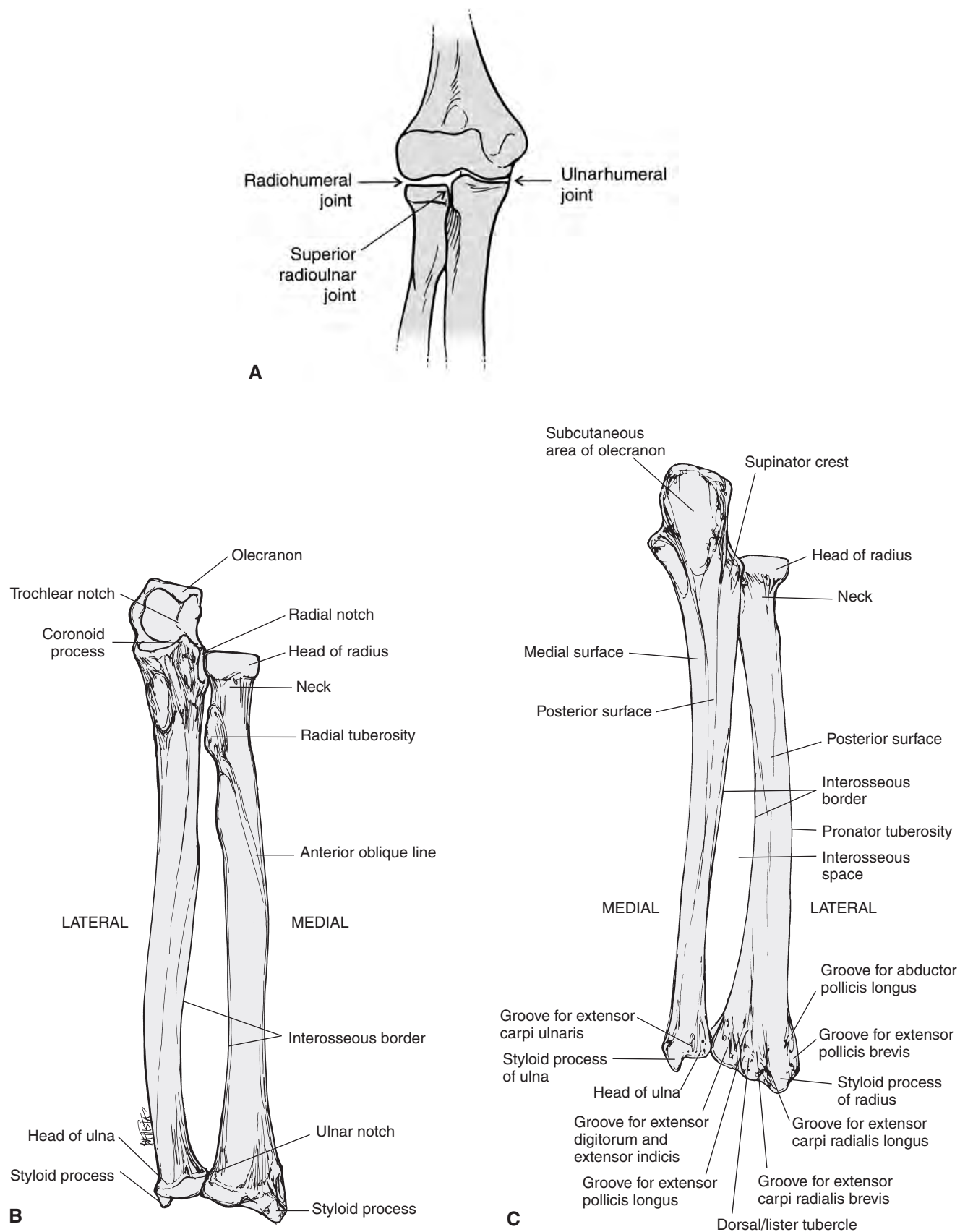


FIGURE 5-15 The radius and ulna articulate with the humerus to form the radiohumeral and ulnar humeral joints. Shown are the elbow joint complex (A) and the anterior (B) and posterior (C) surfaces of the radius and ulna.

the humerus and the **trochlear notch** on the ulna. On the front of the ulna is the **coronoid process**, which makes contact in the **coronoid fossa** of the humerus, limiting flexion in the terminal range of motion. Likewise, on the posterior side of the ulna is the **olecranon process**, which makes contact with the **olecranon fossa** on the humerus, terminating extension. An individual who can hyperextend at the elbow joint may have a small olecranon process or a large olecranon fossa, which allows more extension before contact occurs.

The trochlear notch of the ulna fits snugly around the trochlea, offering good structural stability. The trochlea is covered with articular cartilage over the anterior, inferior, and posterior surfaces and is asymmetrical, with an oblique posterior projection (87). In the extended position, the asymmetrical trochlea creates an angulation of the ulna laterally referred to as a valgus position. This is termed the **carrying angle** and ranges from 10° to 15° in males and 15° to 25° in females (58,87). Measurement of the carrying angle is shown in Figure 5-16. As the forearm flexes, this valgus position is reduced and may even result in a varus position with full flexion (24).

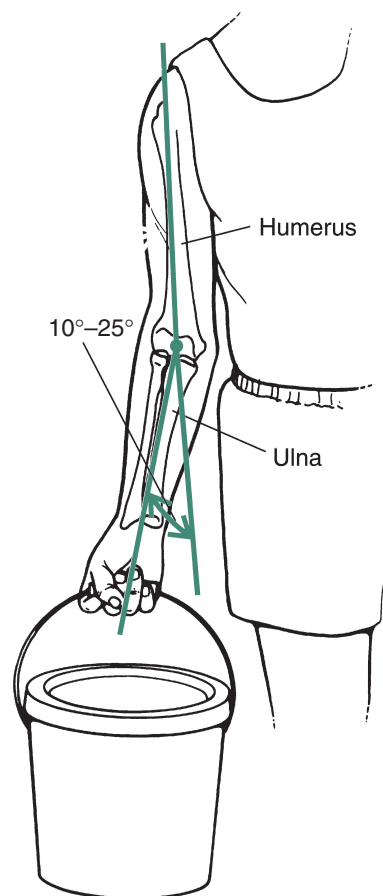


FIGURE 5-16 In the extended position, the ulna and humerus form the carrying angle because of asymmetry in the trochlea. The carrying angle is measured as the angle between a line describing the long axis of the ulna and a line describing the long axis of the humerus. The angle ranges from 10° to 25° .

Radiohumeral Joint

The second joint participating in flexion and extension of the forearm is the **radiohumeral joint**. At the distal end of the humerus is the articulating surface for this joint, the **capitulum**, which is spheroidal and covered with cartilage on the anterior and inferior surfaces. The top of the round radial head butts up against the capitulum, allowing radial movement around the humerus during flexion and extension. The capitulum acts as a buttress for lateral compression and other rotational forces absorbed during throwing and other rapid forearm movements.

Radioulnar Joint

The third articulation, the radioulnar joint, establishes movement between the radius and the ulna in **pronation** and **supination**. There are actually two radioulnar articulations, the superior in the elbow joint region and the inferior near the wrist. Also, midway between the elbow and the wrist is another fibrous connection between the radius and the ulna, recognized by some as a third radioulnar articulation.

The superior or proximal radioulnar joint consists of the articulation between the radial head and the radial fossa on the side of the ulna. The radial head rotates in a fibrous osseous ring and can turn both clockwise and counterclockwise, creating movement of the radius relative to the ulna (12). In the neutral position, the radius and ulna lie next to each other, but in full pronation, the radius has crossed over the ulna diagonally. As the radius crosses over in pronation, the distal end of the ulna moves laterally. The opposite occurs during supination.

An **interosseous membrane** connecting the radius and ulna runs the length of the two bones. This fascia increases the area for muscular attachment and ensures that the radius and ulna maintain a specific relationship to each other. Eighty percent of compressive forces are typically applied to the radius, and the interosseous membrane transmits forces received distally from the radius to the ulna. The membrane is taut in a semiprone position (12).

Two final structural components in the elbow region are the **medial** and **lateral epicondyles**. These are prominent landmarks on the medial and lateral sides of the humerus. The lateral epicondyle serves as a site of attachment for the lateral ligaments and the forearm supinator and extensor muscles, and the medial epicondyle accommodates the medial ligaments and the forearm flexors and pronators (1). These extensions of the humerus are also common sites of overuse injury.

Ligaments and Joint Stability

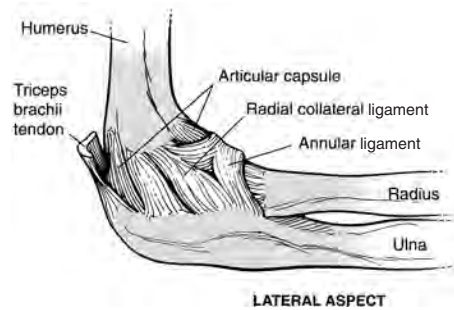
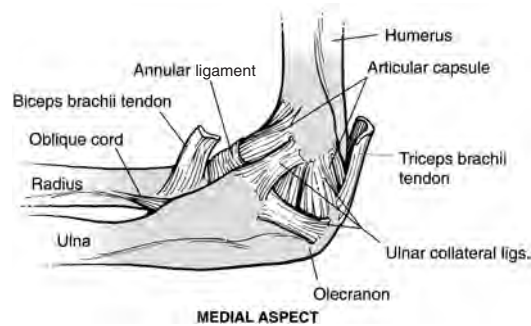
The elbow joint is supported on the medial and lateral sides by collateral ligaments. The medial, or ulnar, collateral ligament (MCL) connects the ulna to the humerus and offers support and resistance to valgus stresses imposed on the elbow joint. Support in the valgus direction is very important in the elbow joint because most forces are directed medially, creating a valgus force. The

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anterior band of the MCL is taut in extension, and the posterior band is relaxed in extension but increases in tension in flexion (1,69). Consequently, the MCL is taut in all joint positions. If the MCL is injured, the radial head becomes important in providing stability when a valgus force is applied (4). The flexor-pronator muscles originating on the medial epicondyle also provide dynamic stabilization to the medial elbow (70).

A set of collateral ligaments on the lateral side of the joint is termed the lateral or radial collateral ligaments. The radial collateral is taut throughout the entire range of flexion (1,69), but because varus stresses are rare, these ligaments are not as significant in supporting the joint (89). The small anconeus muscle provides dynamic stabilization to the lateral elbow (70).

A ligament that is important for the function and support of the radius is the **annular ligament**. This ligament wraps around the head of the radius and attaches to the side of the ulna. The annular ligament holds the radius in the elbow joint while still allowing it to turn in pronation and supination. The elbow ligaments and their actions can be reviewed in Figure 5-17.



Joints Ligament	Insertion	Action
Annular	Anterior margin of radial notch TO posterior margin of radial notch	Surrounds, supports head of radius; maintains radius in joint
Radial collateral	Lateral epicondyle TO annular ligament	Supports lateral joint
Ulnar collateral: Posterior, transverse, anterior	Medial epicondyle; olecranon process TO coronoid process	Supports medial joint, resists valgus forces

FIGURE 5-17 The elbow ligaments.

Movement Characteristics

The three joints of the elbow complex do not all reach a close-packed position (i.e., position of maximum joint surface contact and ligamentous support) at the same point in the range of motion. A close-packed position for the radiohumeral is achieved when the forearm is flexed to 80° and in the semi-pronated position (12). The fully extended position is the close-packed position for the ulnohumeral joint. Thus, when the ulnohumeral articulation is most stable in the extended position, the radiohumeral articulation is loose packed and least stable. The proximal radioulnar joint is in its close-packed position in the semi-pronated position, complementing the close-packed position of the radiohumeral (12).

The range of motion at the elbow in flexion and extension is approximately 145° of active flexion, 160° of passive flexion, and 5° to 10° of hyperextension (12). An extension movement is limited by the joint capsule and the flexor muscles. It is also terminally restrained by bone-on-bone impact with the olecranon process.

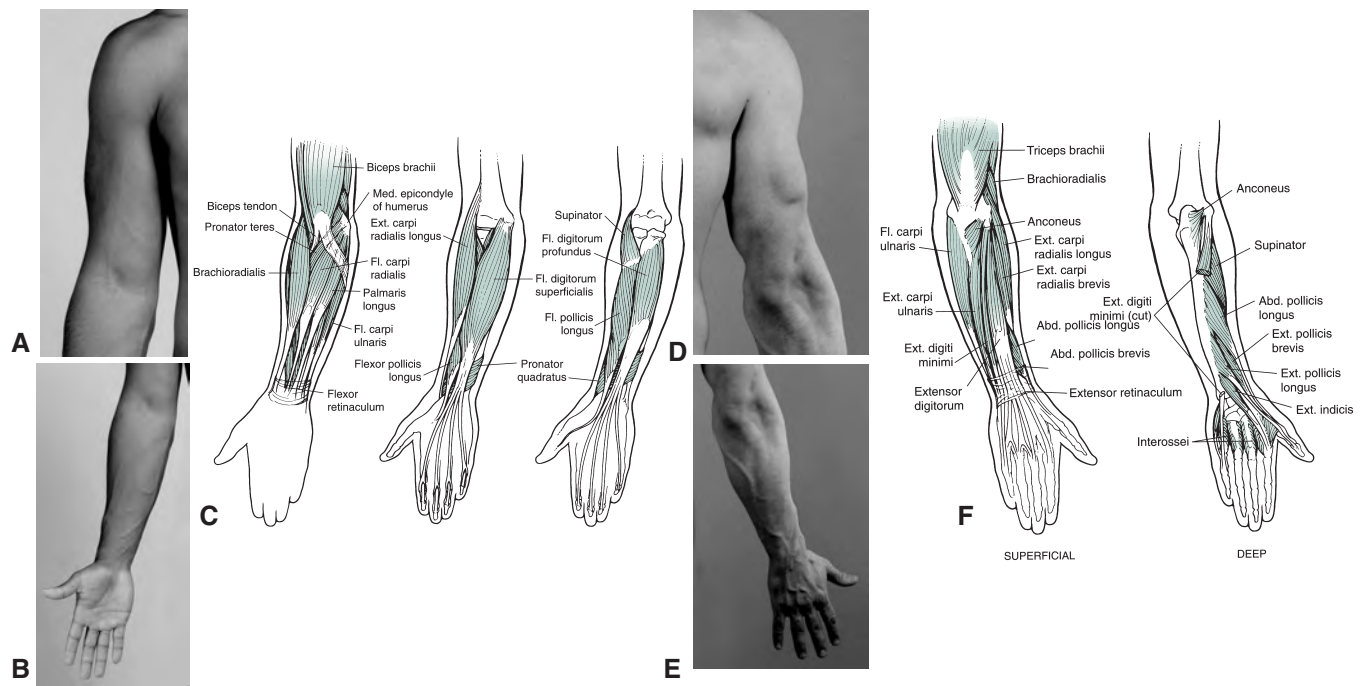
Flexion at the joint is limited by soft tissue, the posterior capsule, the extensor muscles, and the bone-on-bone contact of the coronoid process with its respective fossa. A significant amount of hypertrophy or fatty tissue will limit the range of motion in flexion considerably. Approximately 100° to 140° of flexion and extension is required for most daily activities, but the total range of motion is 30° to 130° of flexion (53).

The range of motion for pronation is approximately 70°, limited by the ligaments, the joint capsule, and soft tissue compressing as the radius and ulna cross. Range of motion for supination is 85° and is limited by ligaments, the capsule, and the pronator muscles. Approximately 50° of pronation and 50° of supination are required to perform most daily activities (89).

MUSCULAR ACTIONS

Twenty-four muscles cross the elbow joint. Some of them act on the elbow joint exclusively; others act at the wrist and finger joints (3). Most of these muscles are capable of producing as many as three movements at the elbow, wrist, or phalangeal joints. One movement is usually dominant, however, and it is the movement with which the muscle or muscle group is associated. There are four main muscle groups, the anterior flexors, posterior extensors, lateral extensor-supinators, and medial flexor-pronators (1). The locations, actions, and nerve supplies of the muscles acting at the elbow joint can be found in Figure 5-18.

The elbow flexors become more effective as elbow flexion increases because their mechanical advantage increases with an increase in the magnitude of the moment arm (3,58). The brachialis has the largest cross-section area of the flexors but has the poorest mechanical advantage. The biceps brachii also has a large cross-section with better mechanical advantage, and the brachioradialis has a



Muscle	Insertion	Nerve Supply	Flexion	Extension	Pronation	Supination
Anconeus	Lateral epicondyle of humerus TO olecranon process on ulna	Radial nerve; C7, C8		Asst		
Biceps brachii	Supraglenoid tubercle; corocoid process TO radial tuberosity	Musculocutaneous nerve: C5, C6	PM			PM
Brachialis	Anterior surface of lower humerus TO coronoid process on ulna	Musculocutaneous nerve: C5, C6	PM			
Brachioradialis	Lateral supracondylar ridge of humerus TO styloid process of radius	Radial nerve; C6, C7	PM			
Extensor carpi radialis brevis	Lateral epicondyle of humerus TO base of 3rd metacarpal	Radial nerve; C6, C7	Asst			
Extensor carpi radialis longus	Lateral supracondylar ridge of humerus TO base of 2nd metacarpal	Radial nerve; C6, C7	Asst			
Extensor carpi ulnaris	Lateral epicondyle of humerus TO base of 5th metacarpal	Posterior interosseous nerve; C6–C8		Asst		
Flexor carpi radialis	Medial epicondyle of humerus TO base of 2nd, 3rd metacarpal	Median nerve; C6, C7	Asst			
Flexor carpi ulnaris	Medial epicondyle TO pisiform; hamate base; base of 5th metacarpal	Ulnar nerve; C8, T1	Asst			
Palmaris longus	Medial epicondyle TO palmar aponeurosis	Median nerve; C6, C7	Asst			
Pronator quadratus	Distal anterior surface of ulna TO distal anterior surface of radius	Anterior interosseous nerve; C8, T1			PM	
Pronator teres	Medial epicondyle of humerus, coronoid process on ulna TO midlateral surface of radius	Median nerve; C6, C7	Asst		PM	
Supinator	Lateral epicondyle of humerus TO upper lateral side of radius	Posterior interosseous nerve; C5, C6				PM

FIGURE 5-18 Elbow and forearm muscles. The anterior surface of the arm (A) and forearm (B) are shown with the anterior muscles (C). The posterior surface of the arm (D) and forearm (E) are shown with the corresponding posterior muscles (F).

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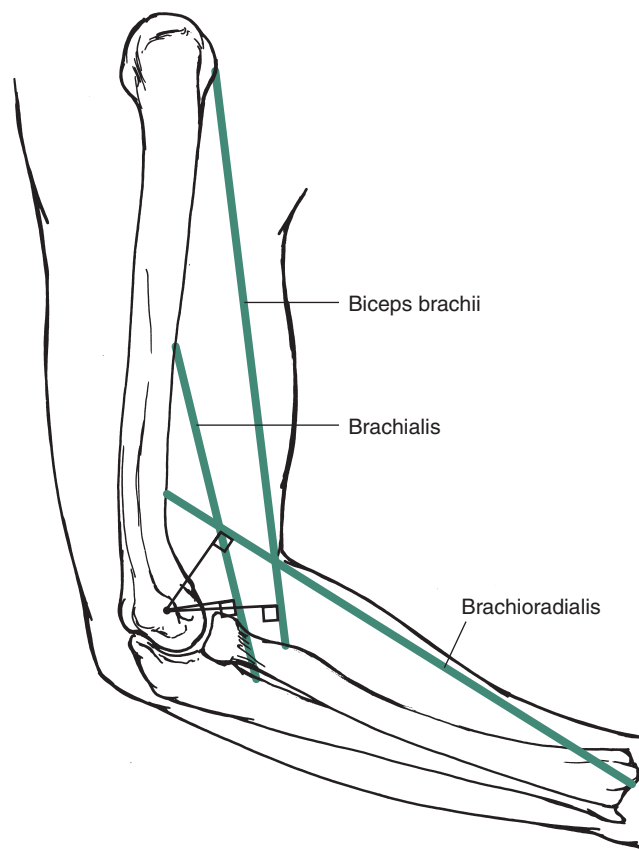


FIGURE 5-19 The line of action of the three forearm muscles. The brachialis (BRA) is a large muscle, but it has the smallest moment arm, giving it the poorest mechanical advantage. The biceps brachii (BIC) also has a large cross-section and has a longer moment arm, but the brachioradialis (BRD), with its smaller cross-section, has the longest moment arm, giving it the best mechanical advantage in this position.

smaller cross-section but the best mechanical advantage (Fig. 5-19). At 100° to 120° of flexion, the mechanical advantage of the flexors is maximal because the moment arms are longer (brachioradialis = 6 cm; brachialis = 2.5–3.0 cm; biceps brachii = 3.5–4.0 cm) (58).

Each of the three main elbow flexors is limited in its contribution to the elbow flexion movement depending on the joint position or mechanical advantage. The brachialis is active in all forearm positions but is limited by its poor mechanical advantage. The brachialis plays a bigger role when the forearm is in the pronated position. The biceps brachii can be limited by actions at both the shoulder and the radioulnar joints. Because the long head of the biceps crosses the shoulder joint, flexion of the shoulder joint generates slack in the long head of the biceps brachii, and extension of the shoulder generates more tension. Because the biceps tendon attaches to the radius, the insertion can be moved in pronation and supination. The influence of pronation on the tendon of the biceps brachii is illustrated in Figure 5-20. Because the tendon wraps around the radius in pronation, the biceps brachii is most effective as a flexor in supination. Finally, the brachioradialis is a muscle with a

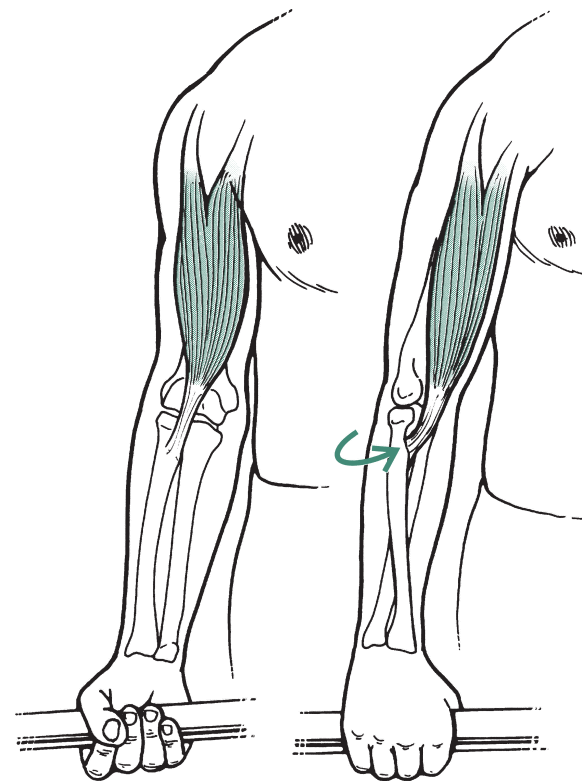


FIGURE 5-20 When the forearm is pronated, the attachment of the biceps brachii to the radius is twisted under. This position interferes with the flexion-producing action of the biceps brachii, which is more efficient in producing flexion when the forearm is supinated and the tendon is not twisted under the radius.

small volume and very long fibers; it is a very efficient muscle, however, because of its excellent mechanical advantage. The brachioradialis flexes the elbow most effectively when the forearm is in midpronation, and it is heavily recruited during rapid movements. It is well positioned to contribute to elbow flexion in the semi-prone position.

In the extensor muscle group is the powerful triceps brachii, the strongest elbow muscle. The triceps brachii has great strength potential and work capacity because of its muscle volume (3). The triceps brachii has three portions: the long head, medial head, and lateral head. Of these three, only the long head crosses the shoulder joint, making it dependent partially on shoulder position for its effectiveness. The long head is the least active of the triceps. However, it can be increasingly more involved with shoulder flexion as its insertion on the shoulder is stretched.

The medial head of the triceps brachii is considered the workhorse of the extension movement because it is active in all positions, at all speeds, and against maximal or minimal resistance. The lateral head of the triceps brachii, although the strongest of the three heads, is relatively inactive unless movement occurs against resistance (73). The output of the triceps brachii is not influenced by forearm positions of pronation and supination.

The medial flexor–pronator muscle group originating on the medial epicondyle includes the pronator teres and three wrist muscles (flexor carpi radialis, flexor carpi ulnaris, palmaris longus). The pronator teres and the three wrist muscles assist in elbow flexion, and the pronator teres and the more distal pronator quadratus are primarily responsible for forearm pronation. The pronator quadratus is more active regardless of forearm position, whether the activity is slow or fast or working against a resistance or not. The pronator teres is called on to become more active when the pronation action becomes rapid or against a high load. The pronator teres is most active at 60° of forearm flexion (74).

The final muscle group at the elbow is the extensor–supinator muscles originating on the lateral epicondyle, which includes the supinator and three wrist muscles (extensor carpi ulnaris, extensor carpi radialis longus, extensor carpi radialis brevis). The wrist muscles can assist with elbow flexion. Supination is produced by the supinator muscle and by the biceps brachii under special circumstances. The supinator is the only muscle that contributes to a slow, unresisted supination action in all forearm positions. The biceps brachii can supinate during rapid or rested movements when the elbow is flexed. The flexion action of the biceps brachii is neutralized by actions from the triceps brachii, allowing contribution to the supination action. At 90° of flexion, the biceps brachii becomes a very effective supinator.

Many of the muscles acting at the elbow joint create multiple movements, and a large number of two-joint muscles also generate movements at two joints. Where an isolated movement is desired, synergistic actions are required to neutralize the unwanted action. For example, the biceps brachii flexes the elbow and supinates the radioulnar joint. To provide a supination movement without flexion, synergistic action from an elbow extensor must occur. Likewise, if flexion is the desired movement, a supination synergist must be recruited. Another example is the biceps brachii action at the shoulder joint where it generates shoulder flexion. To eliminate a shoulder movement during elbow flexion, there must be action from the shoulder extensors. A final example is the triceps brachii action at the shoulder where it creates shoulder extension. If a strong extension is required at the elbow in pushing and throwing actions, shoulder flexors must be engaged to eliminate the shoulder extension movement. If an adjacent joint is to remain stationary, appropriate changes in muscle activity must occur and are usually proportional to the velocity of the movement (26).

STRENGTH OF THE FOREARM MUSCLES

The flexor muscle group is almost twice as strong as the extensors at all joint positions, making us better pullers than pushers. The joint forces created by a maximum isometric flexion in an extended position that is equal to approximately two times body weight.

The semiprone elbow position is the position at which maximum strength in flexion can be developed, followed by the supine position and finally, the pronated position (62). The supine position generates about 20% to 25% more strength than the pronation position. The semiprone position is most commonly used in daily activities. Semiprone flexion exercises should be included in a conditioning routine to take advantage of the strong position of the forearm.

Extension strength is greatest from a position of 90° of flexion (89). This is a common forearm position for daily living activities and for power positions in upper extremity sport skills. Finally, pronation and supination strength is greatest in the semiprone position, with the torque dropping off considerably at the fully pronated or fully supinated position.

CONDITIONING

The effectiveness of exercises used to strengthen or stretch depends on the various positions of the arm and the forearm. In stretching the muscles, the only positions putting any form of stretch on the flexors and extensors must incorporate some hyperextension and flexion at the shoulder joints. Stretching these muscles while the arm is in the neutral position is almost impossible because of the bony restrictions to the range of motion.

The position of the forearm is important in forearm strengthening activities. The forearm position in which the flexors and extensors are the strongest is semiprone. For the flexors specifically, the biceps brachii can be brought more or less into the exercise by supinating or pronating, respectively. Numerous exercises are available for both the flexors and extensors, examples of which are provided in Figure 5-21.

The pronators and supinators offer a greater challenge in the prescription of strength or resistive exercises (Fig. 5-21). Stretching these muscle groups presents no problem because a maximal supination position can adequately stretch the pronation musculature and vice versa. Also, low-resistance exercises can be implemented by applying a force in a turning action (e.g., to a doorknob or some other immovable object). High-resistance exercises necessitate the use of creativity, however, because there are no standardized sets of exercises for these muscles.

INJURY POTENTIAL OF THE FOREARM

There are two categories of injuries at the elbow joint: traumatic or high-force injuries and repetitive or overuse injuries. The elbow joint is subjected to traumatic injuries caused by the absorption of a high force, such as in falling, but most of the injuries at the elbow joint result from repetitive activities, such as throwing or throwing-type actions. The high-impact or traumatic injuries are presented first, followed by the more common overuse injuries.

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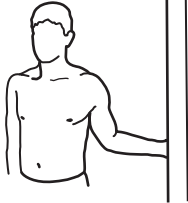






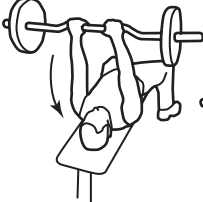
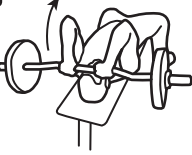



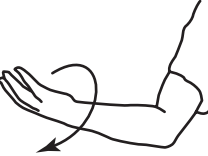


Muscle Group	Sample Stretching Exercise	Sample Strengthening Exercise	Other Exercises
Flexors		<p>Dumbbell biceps curls</p>   <p>Machine biceps curl</p>  	<p>Pull-up Upright row</p>
Extensors	 	<p>Triceps extensions</p>   <p>Triceps push-down</p>  	<p>Push-up Tricep press</p>
Pronators/ supinators	 	<p>Forearm pronation</p>  <p>Forearm supination</p> 	<p>Side-to-side Dumbbells Rice bucket Grabs</p>

FIGURE 5-21 Sample stretching and strengthening exercises for selected muscle flexors, extensors, pronators, and supinators.

One of the injuries occurring as a consequence of absorbing a high force is a dislocation. These injuries usually occur in sports such as gymnastics, football, and wrestling. The athlete falls on an outstretched arm, causing a posterior dislocation (35). With the dislocation, a fracture in the medial epicondyle or the coronoid process may occur. The elbow is the secondly most common dislocated joint in the body (46). Other areas that may fracture with a fall include the olecranon process; the head of the radius; and the shaft of the radius, the ulna, or both. Additionally, spiral fractures of the humerus can be incurred through a fall.

Direct blows to any muscle can culminate in a condition known as myositis ossificans. In this injury, the body deposits **ectopic bone** in the muscle in response to the severe bruising and repeated stress to the muscle tissue. Although it is most common in the quadriceps femoris in the thigh, the brachioradialis muscle in the forearm is the second most common area of the body to develop this condition (35).

A high muscular force can create a **rupture** of the long head of the biceps brachii, commonly seen in adults. The joint movements facilitating this injury are arm hyperextension, forearm extension, and forearm pronation. If these three movements occur concomitantly, the strain on the biceps brachii may be significant. Finally, falling on the elbow can irritate the olecranon bursa, causing **olecranon bursitis**. This injury looks very disabling because of the swelling but is actually minimally painful (12).

The repetitive or overuse injuries occurring at the elbow can be associated with throwing or some overhead movement, such as the tennis serve. Throwing places stringent demands on the medial side of the elbow joint. Through the high-velocity actions of the throw, large tensile forces develop on the medial side of the elbow joint, compressive forces develop on the lateral side of the joint, and shear forces occur on the posterior side of the joint. A maximal valgus force is applied to the medial side of the elbow during the latter part of the cocking phase and through the initial portion of the acceleration phase. The elbow joint is injured because of the change in a varus to a valgus angle, greater forces, smaller contact areas, and contact areas that move more to the periphery as the joint moves through the throwing action (17).

The valgus force is responsible for creating the **medial tension syndrome**, or pitcher's elbow (35,89). This excessive valgus force is responsible for sprain or rupture of the ulnar collateral ligaments, medial **epicondylitis**, **tendinitis** of the forearm or wrist flexors, avulsion fractures to the medial epicondyle, and **osteochondritis dissecans** to the capitulum or olecranon (35,89). The biceps and the pronators are also susceptible to injury because they control the valgus forces and slow down the elbow in extension (45).

Medial epicondylitis is an irritation of the insertion site of the wrist flexor muscles attached to the medial epicondyle. They are stressed with the valgus force accompanied by wrist actions. This injury is seen in the trailing arm during the downswing in golf, in the throwing arm, and as a result of spiking in volleyball. Osteochondritis dissecans, a

lesion in the bone and articular cartilage, commonly occurs on the capitulum as a result of compression during the valgus position that forces the radial head up against the capitulum. During the valgus overload, coupled with forearm extension, the olecranon process can be wedged against the fossa, creating an additional site for osteochondritis dissecans and breakdown in the bone. Additionally, the olecranon is subject to high tensile forces and can develop a **traction apophysitis**, or bony outgrowth, similar to that seen with the patellar ligament of the quadriceps femoris group (35).

The lateral overuse injuries to the elbow usually occur as a consequence of overuse of the wrist extensors at their attachment site on the lateral epicondyle. The overuse of the wrist extensors occurs as they eccentrically slow down or resist any flexion movement at the wrist. Lateral epicondylitis, or tennis elbow, is associated with force overload resulting from improper technique or use of a heavy racquet. If the backhand stroke in tennis is executed with the elbow leading or if the performer hits the ball consistently off center, the wrist extensors and the lateral epicondyle will become irritated (44). Also, a large racquet grip or tight strings may increase the load on the epicondyle by the extensors. Lateral epicondylitis is common in individuals working in occupations such as construction, food processing, and forestry in which repetitive pronation and supination of the forearm accompanies forceful gripping actions. Lateral epicondylitis is seven to 10 times more common than medial epicondylitis (86).



The Wrist and Fingers

The hand is primarily used for manipulation activities requiring very fine movements incorporating a wide variety of hand and finger postures. Consequently, there is much interplay between the wrist joint positions and efficiency of finger actions. The hand region has many stable yet very mobile segments, with complex muscle and joint actions.

ANATOMICAL AND FUNCTIONAL CHARACTERISTICS OF THE JOINTS OF THE WRIST AND HAND

Beginning with the most proximal joints of the hand and working distally to the tips of the fingers offers the best perspective on the interaction between segments and joints in the hand. All of the joints of the hand are illustrated in Figure 5-22. Ligaments and muscle actions for the wrist and hand are illustrated in Figures 5-23 and 5-24, respectively (also see Fig. 5-18).

Radiocarpal Joint

The wrist consists of 10 small carpal bones but can be functionally divided into the **radiocarpal** and the **midcarpal joints**. The radiocarpal joint is the articulation

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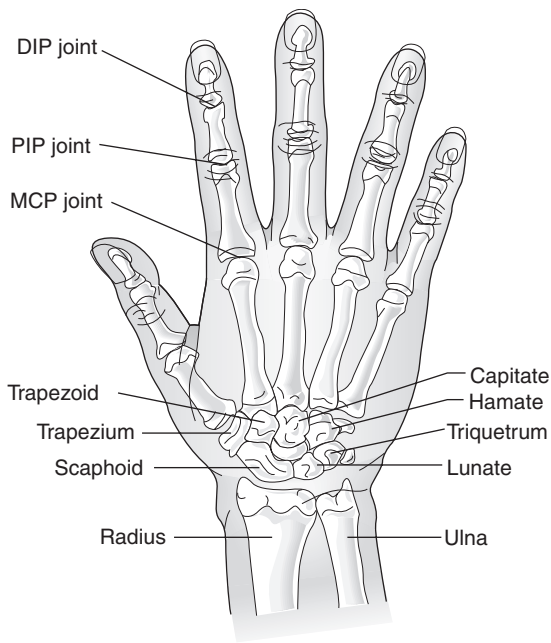


FIGURE 5-22 The wrist and hand can perform both precision and power movements because of numerous joints controlled by a large number of muscles. Most of the muscles originate in the forearm and enter the hand as tendons.

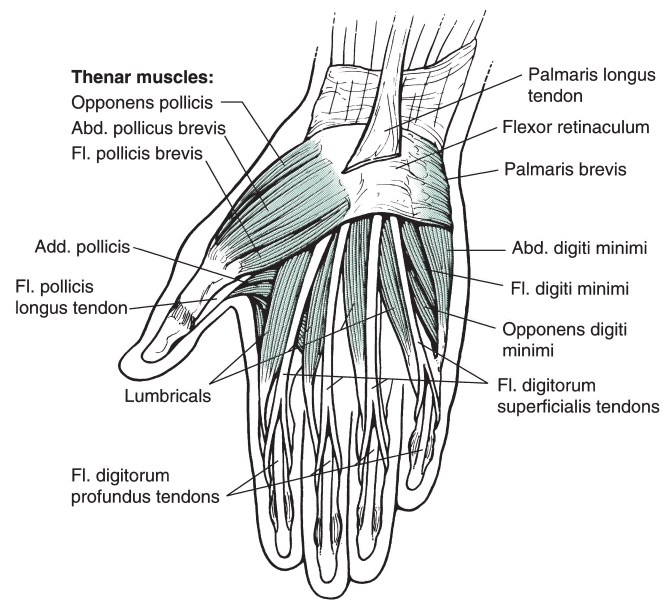
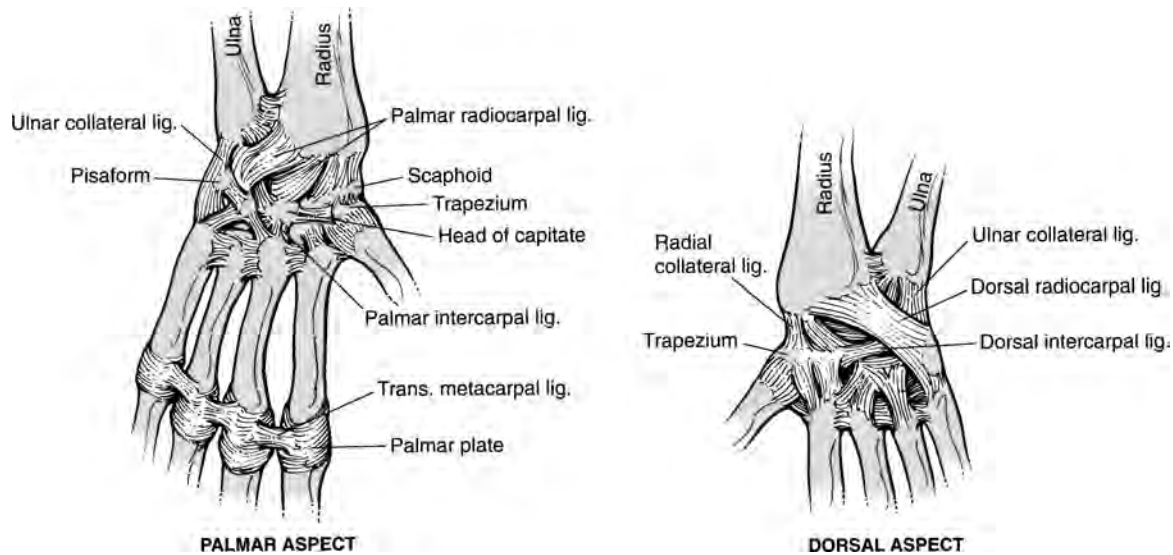


FIGURE 5-24 Muscles of the wrist and hand. Along with insertion and nerve supply, the muscles responsible for the noted movements (PM) and the assisting muscles (Asst) are included in the table on the next page.



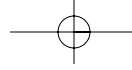
Ligament	Insertion	Action
Collateral	Phalanx TO phalanx; sides of MP, PIP, and DIP joints	Supports sides of fingers; prevents varus, valgus forces
Dorsal intercarpal	First row of carpals TO second row of carpals	Keeps carpals together
Deep transverse	MP of finger TO MP of adjacent finger	Taut in finger flexing, disallowing abduction
Dorsal radiocarpal	Lower end of radius TO scaphoid; lunate; triquetrum	Connects radius to carpals; supports posterior side of wrist
Palmar intercarpal	Scaphoid TO lunate; lunate TO triquetrum	Keeps carpals together
Palmer plates	Across the anterior joint of MP, PIP, DIP	Supports anterior MP, PIP, and DIP joints
Palmar radiocarpal	Lower radius TO scaphoid; lunate; triquetrum	Connects radius to carpals; supports anterior side of wrist
Radial collateral	Radius TO scaphoid; trapezium	Supports lateral side of wrist; resists valgus forces
Ulnar collateral	Ulna TO pisiform; triquetrum	Supports medial side of wrist; resists varus forces

DIP, distal interphalangeal; MP, metacarpophalangeal; PIP, proximal interphalangeal.

FIGURE 5-23 Ligaments of the wrist and hand.

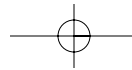
Muscle	Insertion	Muscle	Nerve Supply	Flexion	Extension	Abduction	Adduction	Radial Flexion	Ulnar Flexion	Opposition
Abductor digiti minimi	Pisiform bone TO base of proximal phalanx of little finger		Ulnar nerve; C8, T1	Asst: Little finger MCP		PM: Little finger MCP				
Abductor pollicis brevis	Scaphoid; trapezium TO base of proximal phalanx		Median nerve; C8, T1	Asst: Thumb MCP		PM: Thumb MCP and CMP				
Abductor pollicis longus	Middle of radius TO radial side of base of 1st metacarpal		Posterior interosseous nerve; C6, C7	PM: Wrist	Asst: Thumb CMP	PM: Thumb CMP	PM: Wrist			
Adductor pollicis	Capitate; base of 2nd, 3rd metacarpals TO base of proximal phalanx of thumb		Ulnar nerve; C8, T1			PM: Thumb MCP				
Dorsal interossei	Between metacarpals of four fingers TO base of proximal phalanx of 2nd–4th fingers and extensor hood		Ulnar nerve; C8, T1			PM: Index, ring, middle fingers	PM: Middle finger			
Extensor carpi radialis brevis	Lateral epicondyle of humerus TO base of 3rd metacarpal		Radial nerve; C6, C7		PM: Wrist			PM: Wrist		
Extensor carpi radialis longus	Lateral supracondylar ridge of humerus TO base of 2nd metacarpal		Radial nerve; C6, C7		PM: Wrist			PM: wrist		
Extensor carpi ulnaris	Lateral epicondyle of humerus TO base of 5th metacarpal		Posterior interosseous nerve; C6–C8		PM: Wrist				PM: Wrist	
Extensor digiti minimi	Tendon of extensor digitorum TO proximal phalanx of little finger		Posterior interosseous nerve; C6–C8		PM: Little finger					
Extensor digitorum	Lateral epicondyle of humerus TO dorsal hoods of four fingers		Posterior interosseous nerve; C6–C8		PM: MCP and PIP of four fingers	PM: MCP and PIP of index finger				
Extensor indicis	Lower ulna, interosseous membrane TO dorsal hood of index finger		Posterior interosseous nerve; C6–C8		PM: MCP and PIP of index finger					
Extensor pollicis brevis	Middle of radius, ulna TO base of proximal phalanx of thumb		Posterior interosseous nerve; C6, C7		PM: MCP and IP of thumb		PM: MCP of thumb			(continued)

FIGURE 5-24 (CONTINUED)



Muscle	Insertion	Muscle	Nerve Supply	Flexion	Extension	Abduction	Adduction	Radial Flexion	Ulnar Flexion	Opposition
Extensor pollicis longus	Middle third of ulna, interosseous membrane TO base of distal phalanx of thumb		Posterior interosseous branch of radial nerve; C6–C8		PM: IP and MCP of thumb					
Flexor carpi radialis	Medial epicondyle of humerus TO base of 2nd, 3rd metacarpal		Median nerve; C6, C7	PM: wrist				PM: wrist		
Flexor carpi ulnaris	Medial epicondyle TO pisiform; hamate; base of 5th metacarpal		Ulnar nerve; C8, T1	PM: wrist					PM: wrist	
Flexor digiti minimi brevis	Hamate bone TO proximal phalanx of little finger		Ulnar nerve; C8, T1	PM: little finger MCP						
Flexor digitorum profundus	Anterior, medial ulna TO base of distal phalanx of four fingers		Anterior interosseous nerve; C8, T1; median nerve	PM: PIP and DIP of four fingers						
Flexor digitorum superficialis	Medial epicondyle TO base of middle phalanx of four fingers		Median nerve; C7, C8, T1	PM: MCP and PIP of four fingers						
Flexor pollicis brevis	Trapezium; trapezoid; capitate TO base of proximal phalanx of thumb		Median nerve; C8, T1; ulnar nerve; T1	PM: MCP of thumb						
Flexor pollicis longus	Middle radius, interosseous membrane TO base of distal phalanx of thumb		Anterior interosseous nerve; C8, T1	PM: CMP and PIP of thumb			PM: MCP of thumb			
Lumbricales	Tendon of flexor digitorum profundus TO dorsal hoods of four fingers		Median nerve; C8, T1; ulnar nerve; C8, T1	PM: MCP of four fingers	PM: PIP and DIP of four fingers					
Opponens digiti minimi	Hamate bone TO 5th metacarpal		Ulnar nerve; C8, T1							PM: Little finger
Opponens pollicis	Trapezium TO 1st metacarpal		Median nerve; C8, T1							PM: Thumb
Palmar interossei	Sides of 2nd, 4th, 5th metacarpal TO base of proximal phalanx of same fingers		Ulnar nerve; C8, T1	Asst: MCP of fingers			PM: index, ring, little finger			
Palmaris longus	Medial epicondyle TO palmar aponeurosis		Median nerve; C6, C7	PM: Wrist						

FIGURE 5-24 (CONTINUED)



where movement of the whole hand occurs. The radiocarpal joint involves the broad distal end of the radius and two carpals, the scaphoid and the lunate. There is also minimal contact and involvement with the triquetrum. This ellipsoid joint allows movement in two planes: flexion–extension and radial–ulnar flexion. It should be noted that wrist extension and radial and ulnar flexion primarily occur at the radiocarpal joint but a good portion of the wrist flexion is developed at the midcarpal joints.

Distal Radioulnar Joint

Adjacent to the radiocarpal joint but not participating in any wrist movements is the distal radioulnar articulation. The ulna makes no actual contact with the carpals and is separated by a fibrocartilage disc. This arrangement is important so that the ulna can glide on the disc in pronation and supination while not influencing wrist or carpal movements.

Midcarpal and Intercarpal Joints

To understand wrist joint function, it is necessary to examine the structure and function at the joints between the carpals. There are two rows of carpals, the proximal row, containing the three carpals that participate in wrist joint function (lunate, scaphoid, triquetrum), and the pisiform bone, which sits on the medial side of the hand, serving as a site of muscular attachment. In the distal row, there are also four carpals: the trapezium interfacing with the thumb at the saddle joint, the trapezoid, the capitate, and the hamate.

The articulation between the two rows of carpals is called the **midcarpal joint**, and the articulation between a pair of carpal bones is referred to as an **intercarpal joint**. All of these are gliding joints in which translation movements are produced concomitantly with wrist movements. However, the proximal row of carpals is more mobile than the distal row (82). A concave transverse arch runs across the carpals, forming the carpal arch that determines the floor and walls of the carpal tunnel, through which the tendons of the flexors and the median nerve travel.

The scaphoid may be one of the most important carpals because it supports the weight of the arm, transmits forces received from the hand to the bones of the forearm, and is a key participant in wrist joint actions. The scaphoid supports the weight of the arm and transmits forces when the hand is fixed and the forearm weight is applied to the hand. Because the scaphoid interjects into the distal row of carpals, it sometimes moves with the proximal row and other times with the distal row.

When the hand flexes at the wrist joint, the movement begins at the midcarpal joint. This joint accounts for 60% of the total range of flexion motion (86), and 40% of wrist flexion is attributable to movement of the scaphoid and lunate on the radius. The total range of motion for wrist flexion is 70° to 90°, although it is reported that only 10° to 15° of wrist flexion is needed for most daily activities involving the hand (89). Wrist flexion range of motion is reduced if

flexion is performed with the fingers flexed because of the resistance offered by the finger extensor muscles.

Wrist extension is also initiated at the midcarpal joint, where the capitate moves quickly and becomes close packed with the scaphoid. This action draws the scaphoid into movements of the second row of carpals. This reverses the role of the midcarpal and radiocarpal joints to the extension movement, with more than 60% of the movement produced at the radiocarpal joint and more than 30% at the midcarpal joint (73). This switch is attributed to the fact that the scaphoid moves with the proximal row of carpals in the flexion movement and with the distal row of carpals in extension. The range of motion for extension is approximately 70° to 80°, with approximately 35° of extension needed for daily activities (82). The range of motion of wrist extension is reduced if the extension is performed with the fingers extended.

The hand can also move laterally in radial and ulnar flexion or deviation. These movements are created as the proximal row of carpals glides over the distal row. In the radial flexion movement, the proximal carpal row moves toward the ulna and the distal row moves toward the radius. The opposite occurs for ulnar flexion. The range of motion for radial flexion is approximately 15° to 20° and for ulnar flexion is about 30° to 40° (89).

The close-packed position for the wrist, in which maximal support is offered, is in a hyperextended position. The close-packed position for the midcarpal joint is radial flexion. Both of these positions should be considered when selecting positions that maximize stability in the hand. For example, in racquet sports, the wrist is most stable in a slightly hyperextended position. Also, when one falls on the hand with the arm outstretched and the wrist hyperextended, the wrist—specifically, the scaphoid carpal bone—is especially susceptible to injury because it is in the close-packed position.

Carpometacarpal Joints

Moving distally, the next articulation is the carpometacarpal (CMC) joint, which connects the carpals with each of the five fingers via the metacarpals. Each metacarpal and phalanx is also called a ray. They are numbered from the thumb to the little finger, with the thumb being the first ray and the little finger the fifth. The CMC articulation is the joint that provides the most movement for the thumb and the least movement for the fingers.

For the four fingers, the CMC joint offers very little movement, being a gliding joint that moves directionally with the carpals. The movement is very restricted at the second and third CMC but increases to allow as much as 10° to 30° of flexion and extension at the CMC joint of the ring and little fingers (89). There is also a concave transverse arch across the metacarpals of the fingers similar to that of the carpals. This arch facilitates the gripping potential of the hand.

The CMC joint of the first ray, or thumb, is a saddle joint consisting of the articulation between the trapezium

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and the first metacarpal. It provides the thumb with most of its range of motion, allowing for 50° to 80° of flexion and extension, 40° to 80° of abduction and adduction, and 10° to 15° of rotation (74). The thumb sits at an angle of 60° to 80° to the arch of the hand and has a wide range of functional movements (34).

The thumb can touch each of the fingers in the movement of opposition and is very important in all gripping and prehension tasks. Opposition can take place through a range of motion of approximately 90°. Without the thumb, specifically the movements allowed at the CMC joint, the function of the hand would be very limited.

Metacarpophalangeal Joints

The metacarpals connect with the phalanges to form the **metacarpophalangeal joints** (MCP). Again, the function of the MCP joints of the four fingers differs from that of the thumb. The MCP joints of the four fingers are condyloid joints allowing movements in two planes: flexion–extension and abduction–adduction. The joint is well reinforced on the dorsal side by the dorsal hood of the fingers, on the palmar side by the palmar plates that span the joint, and on the sides by the collateral ligaments or deep transverse ligaments.

The fingers can flex through 70° to 90°, with most flexion in the little finger and least in the index finger (73). Flexion, which determines grip strength, can be more effective and produces more force when the wrist joint is held in 20° to 30° of hyperextension, a position that increases the length of the finger flexors.

Extension of the fingers at the MCP joints can take place through about 25° of motion. The extension can be limited by the position of the wrist. That is, finger extension is limited with the wrist hyperextended and enhanced with the wrist flexed.

The fingers spread in abduction and are brought back together in adduction at the MCP joint. Approximately 20° of abduction and adduction is allowed (82). Abduction is extremely limited if the fingers are flexed because the collateral ligaments become very tight and restrict movement. Thus, the fingers can be abducted when extended and then cannot be abducted or adducted when flexed around an object.

The MCP for the thumb is a hinge joint allowing motion in only one plane. The joint is reinforced with collateral ligaments and the palmar plates but is not connected with the other fingers via the deep transverse ligaments. Approximately 30° to 90° of flexion and 15° of extension can take place at this joint (82).

Interphalangeal Joints

The most distal joints in the upper extremity link are the interphalangeal articulations (IP). Each finger has two IP joints, the proximal interphalangeal (PIP) and the distal **interphalangeal joint** (DIP). The thumb has one IP joint and consequently has only two sections or phalanges, the proximal and distal phalanges. The fingers, however, have

three phalanges, the proximal, middle, and distal. The IP joints are hinge joints allowing for movement in one plane only (flexion and extension), and they are reinforced on the lateral sides of the joints by collateral ligaments that restrict movements other than flexion and extension. The range of motion in flexion of the fingers is 110° at the PIP joint and 90° at the DIP joint and the IP joint of the thumb (82,89).

As with the MCP joint, the flexion strength at these joints determines grip strength. It can be enhanced with the wrist hyperextended by 20° and is impaired if the wrist is flexed. Various finger positions can be obtained through antagonistic and synergistic actions from other muscles so that all fingers can flex or extend at the same time. There can also be extension of the MCP with flexion of the IP and vice versa. There is usually no hyperextension allowed at the IP joints unless an individual has long ligaments that allow extension because of joint laxity.

COMBINED MOVEMENTS OF THE WRIST AND HAND

The wrist position influences the position of the metacarpal joints, and the metacarpal joints influence the position of the IP joints. This requires a balance between muscle groups. The wrist movements are usually reverse those of the fingers because the extrinsic muscle tendons are not long enough to allow the full range of motion at the wrist and fingers (76,77). Thus, complete flexion of the fingers is generally only possible if the wrist in slight extension, and extension of the fingers is facilitated with synergistic action from the wrist extensors.

MUSCULAR ACTIONS

Most of the muscles that act at the wrist and finger joints originate outside the hand in the region of the elbow joint and are termed extrinsic muscles (see Fig. 5-24). These muscles enter the hand as tendons that can be quite long, as in the case of some finger tendons that eventually terminate on the distal tip of a finger. The tendons are held in place on the dorsal and palmar wrist area by extensor and flexor retinacula. These are bands of fibrous tissue running transversely across the distal forearm and wrist that keep the tendons close to the joint. During wrist and finger movements, the tendons move through considerable distances but are still maintained by the retinacula. Thirty-nine muscles work the wrist and hand, and no muscle works alone; antagonists and agonists work in pairs. Even the smallest and simplest movement requires antagonistic and agonistic action (76). The extrinsic muscles provide considerable strength and dexterity to the fingers without adding muscle bulk to the hand.

In addition to the muscles originating in the forearm, intrinsic muscles originating within the hand create movement at the MCP and IP joints. The four intrinsic muscles of the thumb form the fleshy region in the palm known as

the **thenar eminence**. Three intrinsic muscles of the little finger form the smaller **hypothenar eminence**, the fleshy ridge on the little finger side of the palm.

The wrist flexors (flexor carpi ulnaris, flexor carpi radialis, palmaris longus) are all fusiform muscles originating in the vicinity of the medial epicondyle on the humerus. These muscles run about halfway along the forearm before becoming a tendon. The flexor carpi radialis and flexor carpi ulnaris contribute the most to wrist flexion. The palmaris longus is variable and may be as small as a tendon or even absent in about 13% of the population (73). The strongest flexor of the group, the flexor carpi ulnaris, gains some of its power by encasing the pisiform bone and using it as a sesamoid bone to increase mechanical advantage and reduce the overall tension on the tendon. Because most activities require the use of a small amount of wrist flexion, attention should always be given to the conditioning of this muscle group.

The wrist extensors (extensor carpi ulnaris, extensor carpi radialis longus, extensor carpi radialis brevis) originate in the vicinity of the lateral epicondyle. These muscles become tendons about one third of the way along the forearm. The wrist extensors also act and create movements at the elbow joint. Thus, elbow joint position is important for wrist extensor function. The extensor carpi radialis longus and extensor carpi radialis brevis create flexion at the elbow joint and thus can be enhanced as a wrist extensor with extension at the elbow. The extensor carpi ulnaris creates extension at the elbow and is enhanced as a wrist extensor in elbow flexion. Also, wrist extension is an important action accompanying and supporting a gripping action using finger flexion. Thus, the wrist extensor muscles are active with this activity.

The wrist flexors and extensors pair up to produce ulnar and radial flexion. Ulnar flexion is produced by the ulnar wrist muscles, consisting of the flexor carpi ulnaris and the extensor carpi ulnaris. Likewise, radial flexion is produced by the flexor carpi radialis, extensor carpi radialis longus, and extensor carpi radialis brevis. Radial flexion joint movement, although it has just half the range of motion of ulnar flexion, is important in many racquet sports because it creates the close-packed position of the wrist, thus stabilizing the hand (82).

Finger flexion is performed primarily by the flexor digitorum profundus and flexor digitorum superficialis. These extrinsic muscles originate in the vicinity of the medial epicondyle. The flexor digitorum profundus cannot independently flex each finger. Thus, flexion at the middle, ring, and little fingers usually occurs together because the flexor tendons all arise from a common tendon and muscle. Because of the separation of the flexor digitorum profundus muscle and tendon for this digit, the index finger can independently flex.

The flexor digitorum superficialis is capable of flexing each finger independently. The fingers can be independently flexed at the PIP but not at the DIP joint. Flexion of the little finger is also assisted by one of the intrinsic

muscles, the flexor digiti minimi brevis. Flexion of the fingers at the MCP articulation is produced by the lumbricales and the interossei, two sets of intrinsic muscles that lie in the palm and between the metacarpals. These muscles also produce extension at the IP joints because they attach to the fibrous extensor hood running the length of the dorsal surface of the fingers. Consequently, to achieve full flexion of the MCP, PIP, and DIP joints, the long finger flexors must override the extension component of the lumbricales and interossei. This is easier if tension is taken off the extensors by some wrist extension.

Extension of the fingers is created primarily by the extensor digitorum muscle. This muscle originates at the lateral epicondyle and enters the hand as four tendon slips that branch off at the MCP articulation. The tendons create a main slip that inserts into the extensor hood and two collateral slips that connect into adjacent fingers. The extensor hood, formed by the tendon of the extensor digitorum and fibrous connective tissue, wraps around the dorsal surface of the phalanges and runs the total length of the finger to the distal phalanx. The structures in the finger are shown in Figure 5-25.

Because the lumbricales and interossei connect into this hood, they also assist with extension of the PIP and DIP joints. Their actions are facilitated as the extensor digitorum contracts, applying tension to the extensor hood and stretching these muscles (82).

Abduction of fingers two, three, and four is performed by the dorsal interossei. The dorsal interossei consist of four intrinsic muscles lying between the metacarpals. They connect to the lateral sides of digits two and four and to both sides of digit three. The little finger, digit five, is abducted by one of its intrinsic muscles, the abductor digiti minimi brevis.

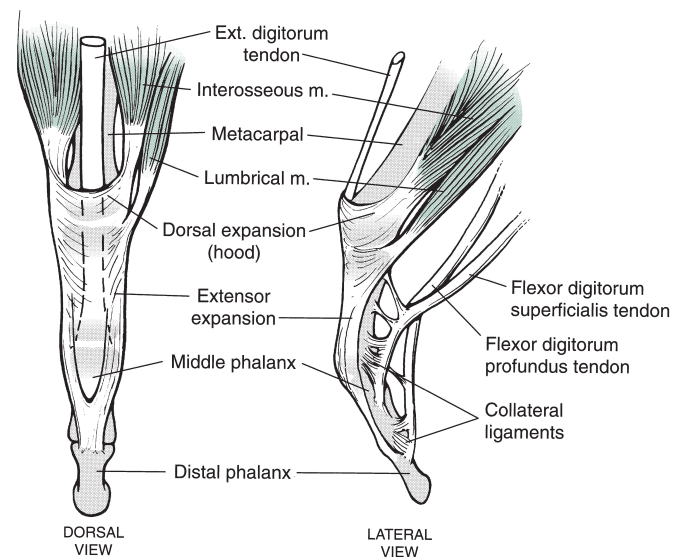


FIGURE 5-25 There are no muscle bellies in the fingers. On the dorsal surface of the fingers are the extensor expansion and the extensor hood, to which the finger extensors attach. Tendons of the finger flexors travel the ventral surface of the fingers. The fingers flex and extend as tension is generated in the tendons via muscular activity in the upper forearm.

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The three palmar interossei, lying on the medial side of digits two, four, and five, pull the fingers back into adduction. The middle finger is adducted by the dorsal interossei, which is connected to both sides of the middle finger. Abduction and adduction movements are necessary for grasping, catching, and gripping objects. When the fingers are flexed, abduction is severely limited by the tightening of the collateral ligament and the limited length-tension relationship in the interossei, which are also flexors of the MCP joint.

The thumb has eight muscles that control and generate an expansive array of movements. The muscles of the thumb are presented in Figure 5-24. Opposition is the most important movement of the thumb because it provides the opportunity to pinch, grasp, or grip an object by bringing the thumb across to meet any of the fingers. Although all of the hypothenar muscles contribute to opposition, the main muscle responsible for initiating the movement is the *opponens pollicis*. The little finger is also assisted in opposition by the *opponens digiti minimi*.

STRENGTH OF THE HAND AND FINGERS

Strength in the hand is usually associated with grip strength, and there are many ways to grasp or grip an object. Whereas a firm grip requiring maximum output uses the extrinsic muscles, fine movements, such as a pinch, use more of the intrinsic muscles to fine-tune the movements.

In a grip, the fingers flex to wrap around an object. If a **power grip** is needed, the fingers flex more, with the most powerful grip being the fist position with flexion at all three finger joints, the MP, PIP, and DIP. If a fine **precision grip** is required, there may be only limited flexion at the PIP and DIP joints, and only one or two fingers may be involved, such as in pinching and writing (89). Examples of both power and precision grips are shown in Figure 5-26. The thumb determines whether a fine precision position or power position is generated. If the thumb remains in the plane of the hand in an adducted position and the fingers flex around an object, a power position is created. An example of this is the grip used in the javelin throw and in the golf swing. This power position still allows for some precision, which is important in directing the golf club or the javelin.

Power in the grip can be enhanced by producing a fist with the thumb wrapped over the fully flexed fingers. With this grip, there is minimal, if any, precision. In activities that require precise actions, the thumb is held more perpendicular to the hand and moved into opposition, with limited flexion at the fingers. An example of this type of position is in pitching, writing, and pinching. In a pinch or prehensile grip, greater force can be generated if the pulp of the thumb is placed against the pulps of the index and long fingers. This pinch is 40% stronger than the pinch grip with the tips of the thumb and fingers (39).

The strength of a grip can be enhanced by the position of the wrist. Placing the wrist in slight extension and ulnar

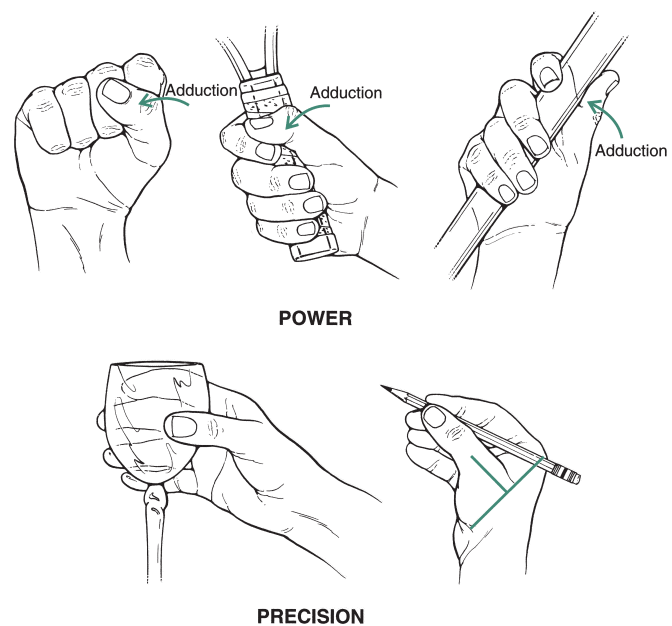


FIGURE 5-26 If power is needed in a grip, the fingers flex at all three joints to form a fist. Also, if the thumb adducts, the grip is more powerful. A precision grip usually involves slight flexion at a small number of finger joints with the thumb perpendicular to the hand.

flexion increases the finger flexion strength. The least finger strength can be generated in a flexed and radial flexed wrist position. Grip strength at approximately 40° of wrist hyperextension is more than three times that of grip strength measured in 40° of wrist flexion (89). The strength of the grip may increase with specific wrist positioning, but the incidence of strain or impingement on structures around the wrist also increases. The neutral position of the wrist is the safest position because it reduces strain on the wrist structures.

The strongest muscles in the hand region, capable of the greatest work capacity, in order from high to low are the *flexor digitorum profundus*, *flexor carpi ulnaris*, *extensor digitorum*, *flexor pollicis longus*, *extensor carpi ulnaris*, and *extensor carpi radialis longus*. Two muscles that are weak and capable of little work capacity are the *palmaris longus* and the *extensor pollicis longus*.

CONDITIONING

There are three main reasons people condition the hand region. First, the fingers can be strengthened to enhance the grip strength in athletes who participate in racquet sports, individuals who work with implements, and individuals who lack the ability to grasp or grip objects.

Second, the muscles acting at the wrist joint are usually strengthened and stretched to facilitate a wrist position for racquet sports or to enhance wrist action in a throwing or striking event, such as volleyball. Wrist extension draws the hand back, and wrist flexion snaps the hand forward in activities such as serving and spiking in volleyball, dribbling in basketball, and throwing a baseball. Even though the speed of the flexion and extension movement may be

determined by contributions from adjacent joints, strengthening the wrist flexor and extensor muscles enhances the force production. Commonly, the wrist is maintained in a position so that an efficient force application can occur. In tennis and racquet sports, for example, the wrist is held either in the neutral position or in a slightly radially flexed position. If the wrist is held stationary, the force applied to the ball by the racquet will not be lost through movements occurring at the wrist. This position is maintained by both the wrist flexor and wrist extensor muscles. Another example of maintaining wrist position is in the volleyball underhand pass, in which the wrist is maintained in an ulnar flexed position. This opens up a broader area for contact and locks the elbows so they maintain an extended position upon contact. The wrist must be maintained in a stable, static position to achieve maximal performance from the fingers. Thus, while playing a piano or typing, the wrist must be maintained in the optimal position for finger usage. This is usually a slight hyperextended position via the wrist extensors.

The final reason for conditioning the hand region is to reduce or prevent injury. The tension developed in the hand and finger flexor and extensor muscles places considerable strain on the medial and lateral aspect of the elbow joint. Some of this strain can be reduced through stretching and strengthening exercises.

Overall, the conditioning of the hand region is relatively simple and can be done in a very limited environment with minimal equipment. Examples of some flexibility and resistance exercises for the wrist flexors and extensors and the fingers are presented in Figure 5-27. Wrist curls and tennis ball gripping exercises are the most popular for this region.

INJURY POTENTIAL OF THE HAND AND FINGERS

Many injuries can occur to the hand as a result of absorbing a blunt force, as in impact with a ball, the ground, or another object. Injuries of this type in the wrist region are usually associated with a fall, forcing the wrist into extreme flexion or extension. In this case, extreme hyperextension is the most common injury. This can result in a sprain of the wrist ligaments, a strain of the wrist muscles, a fracture of the scaphoid (70%) or other carpals (30%), a fracture of the distal radius, or a dislocation between the carpals and the wrist or other carpals (48).

The distal end of the radius is one of the most frequently fractured areas of the body because the bone is not dense and the force of the fall is absorbed by the radius. A common fracture of the radius, Colles' fracture, is a diagonal fracture that forces the radius into more radial flexion and shortens it. These injuries are associated mainly with activities such as hockey, fencing, football, rugby, skiing, soccer, bicycling, parachuting, mountain climbing, and hang gliding, in which the chance of a blunt macrotrauma is greater than in other activities.

Examples of injuries to the fingers and the thumb as a result of blunt impact are fractures, dislocations, and tendon avulsions. The thumb can be injured by jamming it or forcing it into extension, causing severe strain of the thenar muscles and the ligaments surrounding the MCP joint. **Bennett's fracture** is a common fracture to the thumb at the base of the first metacarpal. Thumb injuries caused by jamming by the pole are common in skiing (83). Thumb injuries are also common in biking (71).

The fingers are also frequently fractured or dislocated by an impact on the tip of the finger, forcing it into extreme flexion or extension. Fractures are relatively common in the proximal phalanx and rare in the middle phalanx. High-impact collisions with the hand, such as in boxing and the martial arts, result in more fractures or dislocations of the ring and little fingers because they are least supported in a fist position.

Finger flexor or extensor mechanisms can be disrupted with a blow, forcing the finger into extreme positions. **Mallet finger** is an avulsion injury to the extensor tendon at the distal phalanx caused by forced flexion, resulting in the loss of the ability to extend the finger. **Boutonniere deformity**, caused by avulsion or stretching of the middle branch of the extensor mechanism, creates a stiff and immobile PIP articulation (73). Avulsion of the finger flexors is called **jersey finger** and is caused by forced hyperextension of the distal phalanx. The finger flexors can also develop nodules, a **trigger finger**. This results in snapping during flexion and extension of the fingers. These finger and thumb injuries are also commonly associated with the sports and activities listed above because of the incidence of impact occurring to the hand region.

There are also overuse injuries associated with repetitive use of the hand in sports, work, or other activities. **Tenosynovitis** of the radial flexors and thumb muscles is common in activities such as canoeing, rowing, rodeo, tennis, and fencing. Tennis and other racquet sports, golf, throwing, javelin, and hockey, in which the wrist flexors and extensors are used to stabilize the wrist or create a repetitive wrist action, are susceptible to tendinitis of the wrist muscles inserting into the medial and lateral epicondyles. Medial or lateral epicondylitis may also result from this overuse. Medial epicondylitis is associated with overuse of the wrist flexors, and lateral epicondylitis is associated with overuse of the wrist extensors.

A disabling overuse injury to the hand is **carpal tunnel syndrome**. Next to low-back injuries, carpal tunnel syndrome is one of the most frequent work injuries reported by the medical profession. The floor and sides of the carpal tunnel are formed by the carpals, and the top is formed by the transverse carpal ligament. Traveling through this tunnel are all of the wrist flexor tendons and the median nerve (Fig. 5-28). Through repetitive actions at the wrist, usually repeated wrist flexion, the wrist flexor tendons may be inflamed to the point where there is pressure and constriction of the median nerve. The median nerve innervates the radial side of the hand, specifically the thenar muscles

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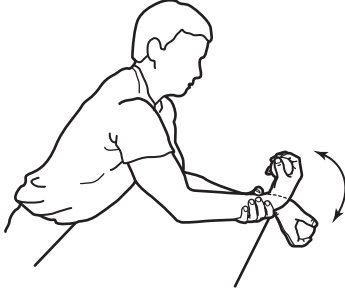
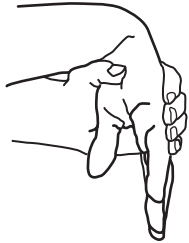
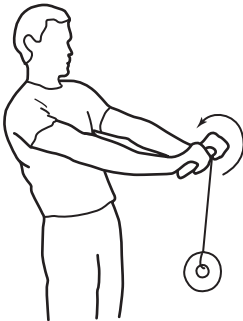
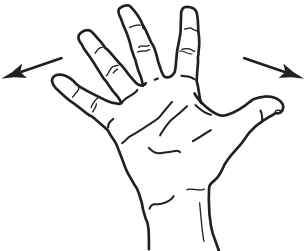

Muscle Group	Sample Stretching Exercise	Sample Strengthening Exercise	Other Exercises
Flexors			Rice bucket grabs Manual resistance
Extensors			Fold hands together Reverse curl
Finger flexors	<p data-bbox="548 1256 736 1311">Straighten all fingers Spread all fingers</p>   <p data-bbox="548 1942 755 1970">Large circle with thumb</p>	Ball squeeze	Make a fist

FIGURE 5-27 Sample stretching and strengthening exercises for wrist flexors and extensors and the finger flexors.

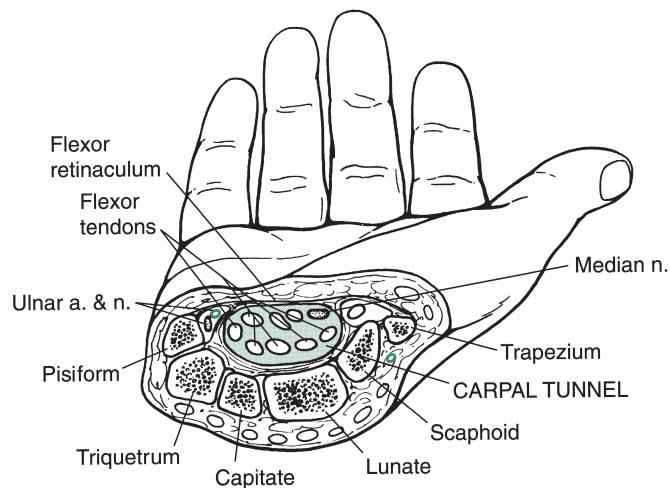
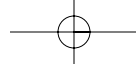


FIGURE 5-28 The floor and sides of the carpal tunnel are formed by the carpals, and the top of the tunnel is covered by ligament and the flexor retinaculum. Within the tunnel are wrist flexor tendons and the median nerve. Overuse of the wrist flexors can impinge the median nerve, causing carpal tunnel syndrome.

of the thumb. Impingement of this nerve can cause pain, atrophy of the thenar muscles, and tingling sensations in the radial side of the hand.

To eliminate this condition, the source of the irritation must be removed by examining the workplace environment; a wrist stabilizing device can be applied to reduce the magnitude of the flexor forces; or a surgical release can be administered. It is recommended that the wrist be maintained in a neutral position while performing tasks in the workplace to avoid carpal tunnel syndrome.

Ulnar nerve injuries can also result in loss of function to the ulnar side of the hand, specifically the ring and little finger. Damage to this nerve can occur as a result of trauma to the elbow or shoulder region. Ulnar neuropathy is associated with activities such as cycling (56).

Contribution of Upper Extremity Musculature to Sport Skills or Movements



To fully appreciate the contribution of a muscle or muscle group to an activity, the activity or movement of interest must be evaluated and studied. This provides an understanding of the functional aspect of the movement, ideas for training and conditioning of the appropriate musculature, and a better comprehension of injury sites and mechanisms. The upper extremity muscles are important for the completion of many daily activities. For example, pushing up to get out of a chair or a wheelchair places a tremendous load on the upper extremity muscles because the full body weight is supported in the transfer from a sitting to a standing position (5,25). If you simply push up out of a chair or wheelchair, the muscle primarily used is the triceps brachii, followed by the pectoralis major, with some minimal contribution from the latissimus dorsi.

Upper extremity muscles are important contributors to a variety of physical activities. For example, in freestyle swimming, propelling forces are generated by the motion of the arms through the water. Internal rotation and adduction are the primary movements in the propulsion phase of swimming and use the latissimus dorsi, teres major, and pectoralis major muscles (55,61). Also, as the arm is taken out of the water to prepare for the next stroke, the supraspinatus and infraspinatus (abduction and external rotation of the humerus), middle deltoid (abduction), and serratus anterior (very active in the hand lift as it rotates the scapula) are active. Swimming incorporates a high amount of upper extremity muscle actions.

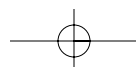
A more thorough review of muscular activity is provided for the overhand throw and the golf swing. These are examples of a functional anatomy description of a movement and are gathered primarily from electromyographic research. Each activity is first broken down into phases. Next, the level of activity in the muscle is described as being low, moderate, or high. Finally, the action of the muscle is identified along with the movement it is concentrically generating or eccentrically controlling. It is important to note that these examples may not include all of the muscles that might be active in these activities but only the major contributing muscles.

OVERHAND THROWING

Throwing places a great deal of strain on the shoulder joint and requires significant upper extremity muscular action to control and contribute to the throwing movement even though the lower extremity is a major contributor to the power generation in a throw.

The throwing action described in this section is a pitch in baseball from the perspective of a right-hand thrower (Fig. 5-29). From the windup through the early cocking phases, the front leg strides forward and the hand and ball are moved as far back behind the body as possible. In late cocking, the trunk and legs rotate forward as the arm is maximally abducted and externally rotated (21,22,55). In these phases, the deltoid and the supraspinatus muscles are active in producing the abduction of the arm. The infraspinatus and the teres minor are also active, assisting with abduction and initiating the external rotation action. The subscapularis is also minimally active to assist during the shoulder abduction. During the late cocking phase, the latissimus dorsi and the pectoralis major muscles demonstrate a rapid increase in activity as they eccentrically act to slow the backward arm movement and concentrically act to initiate forward movement.

In the cocking phase of the throw, the biceps brachii and the brachialis are active as the forearm flexes and the arm is abducted. The activity of the triceps brachii begins at the end of the cocking phase, when the arm is in maximum external rotation and the elbow is maximally flexed. There is a co-contraction of the biceps brachii and the triceps brachii at this time. Additionally, the forearm is



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pronated to 90° at the end of the cocking phase via the pronator teres and pronator quadratus (37,54).

Muscles previously active in the early portion of the cocking phase also change their level of activity as the arm nears the completion of this phase. Teres minor and infraspinatus activity increase at the end of the cocking phase to generate maximal external rotation. The activity of the supraspinatus increases as it maintains the abduction late into the cocking phase. Subscapularis activity also increases to maximum levels in preparation for the acceleration of the arm forward. The deltoid is the only muscle whose activity diminishes late in the cocking phase (55).

At the end of the cocking phase, the external rotation motion is terminated by the anterior capsule and ligaments and the actions of the subscapularis, pectoralis major, triceps brachii, teres major, and latissimus dorsi muscles. Consequently, in this phase of throwing, the anterior capsule

and ligaments and the tissue of the specified muscles are at greatest risk for injury (21,55). Examples of injuries developing in this phase are tendinitis of the insertion of the subscapularis and strain of the pectoralis major, teres major, or latissimus dorsi muscle.

The acceleration phase is an explosive action characterized by the initiation of elbow extension, arm internal rotation with maintenance of 90° of abduction, scapula protraction or abduction, and some horizontal flexion as the arm moves forward. The muscles most active in the acceleration phase are those that act late in the cocking phase, including the subscapularis, latissimus dorsi, teres major, and pectoralis major, which generate the horizontal flexion and the internal rotation movements; the serratus anterior, which pulls the scapula forward into protraction or abduction; and the triceps brachii, which initiates and controls the extension of the forearm. Sites of

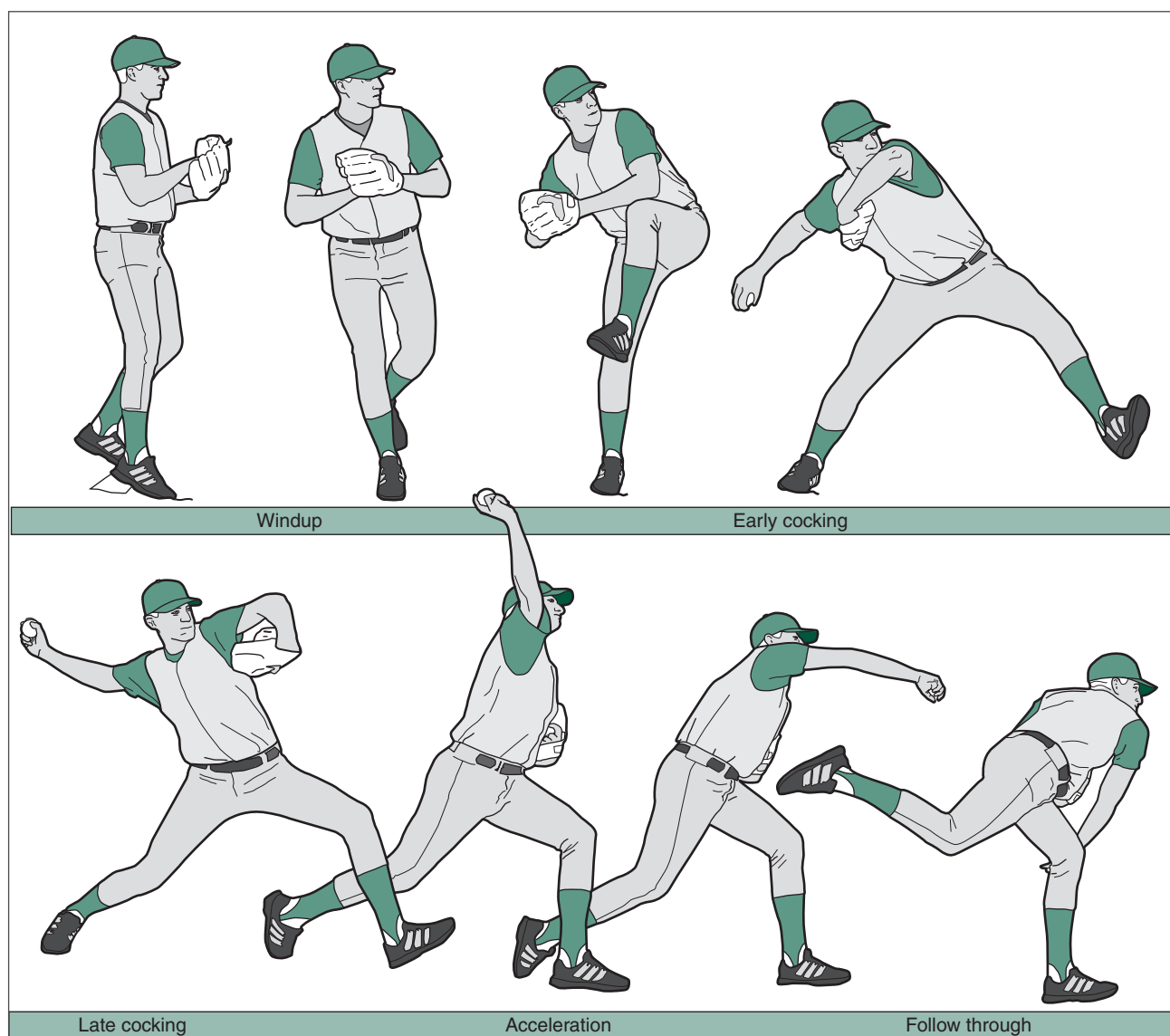


FIGURE 5-29 Upper extremity muscles involved in the overhead throw showing the level of muscle activity (low, moderate, high) and the type of muscle action (concentric [CON] and eccentric [ECC]) with the associated purpose.

Muscle	Windup: Start of Motion to Max Knee Lift of Lead Leg; Arms Raised Together			Early Cocking: Lead Leg Moves Forward and Arms Separate to Abduct and Externally Rotate			Late cocking: Trunk and Legs Rotated Forward with Arm Maximally Abducted, Horizontally Abducted and Externally Rotated			Acceleration: Trunk Flexion with Shoulder Internal Rotation and Elbow Extension			Follow-through/Deceleration: Trunk Continues to Flex with Shoulder Internal Rotation and Horizontal Adduction and Elbow Extension		
	Level	Action	Purpose	Level	Action	Purpose	Level	Action	Purpose	Level	Action	Purpose	Level	Action	Purpose
Biceps Brachii	Low	CON	Elbow Flexion	High	ECC	Counteract valgus at elbow	Med	ECC	Control of Shoulder External Rotation by long head				High	ECC	Control of elbow extension
Deltoid	Low	CON	Shoulder Abduction	High	CON	Shoulder Abduction	Low	CON	Elbow flexion Shoulder Abduction and stabilize shoulder	High	CON	Shoulder Abduction	Med	CON	Stabilize Shoulder
Infraspinatus				Low	CON	Shoulder Horizontal Abduction; External Rotation	High	CON	Shoulder Horizontal Abduction; External Rotation				High	ECC	Control of Horizontal Adduction
Lattissimus Dorsi/Teres Major	Low	CON	Shoulder Internal Rotation				Med	ECC	Control of Shoulder External Rotation	High	CON	Shoulder Internal Rotation	Med	CON	Stabilize Shoulder Joint
Pectoralis Major							Med	ECC	Control of Shoulder Horizontal Abduction	High	CON	Shoulder Horizontal Adduction			
Serratus Anterior				Medium	CON	Scapula Upward Rotation	Med	CON	Scapula Upward Rotation	High	CON	Scapula Abduction			
Subscapularis							Low	ECC	Control of Shoulder External Rotation	High	CON	Internal Rotation	High	CON	Internal Rotation

(continued)

Muscle	Windup: Start of Motion to Max Knee Lift of Lead Leg; Arms Raised Together			Early Cocking: Lead Leg Moves Forward and Arms Separate to Abduct and Externally Rotate			Late Cocking: Trunk and Legs Rotated Forward with Arm Maximally Abducted, Horizontally Abducted and Externally Rotated			Acceleration: Trunk Flexion with Shoulder Internal Rotation and Elbow Extension			Follow-through/Deceleration: Trunk Continues to Flex with Shoulder Internal Rotation and Horizontal Adduction and Elbow Extension		
	Level	Action	Purpose	Level	Action	Purpose	Level	Action	Purpose	Level	Action	Purpose	Level	Action	Purpose
Supraspinatus	Low	CON	Shoulder Abduction	High	CON	Shoulder Abduction	High	CON	Shoulder Abduction	High	CON	Shoulder Abduction	High	ECC	Control of Horizontal Adduction and Internal Rotation
Teres Minor	Low	CON	Shoulder Horizontal Abduction; External Rotation	High	CON	Shoulder Horizontal Abduction; External Rotation	High	CON	Shoulder Horizontal Abduction; External Rotation	High	CON	Shoulder Horizontal Abduction; External Rotation	High	ECC	Control of Horizontal Adduction and Internal Rotation
Trapezius	Medium	CON	Scapula Upward Rotation	Med	CON	Scapula Upward Rotation and Elevation	Med	CON	Scapula Upward Rotation and Elevation	High	CON	Scapula Upward Rotation and Elevation	High	ECC	Control of Horizontal Adduction and Internal Rotation
Triceps Brachii				Med	ECC	Control of Elbow Flexion	Med	ECC	Control of Elbow Flexion	High	CON	Elbow Extension	High	ECC	Control of Wrist Flexion
Wrist/Finger Extensors	High	CON	Wrist Hyperextension	High	CON	Wrist Hyperextension	High	CON	Wrist Hyperextension	High	ECC	Control of Wrist Hyperextension	High	ECC	Control of Wrist Flexion
Wrist/Finger Flexors															

Sources: Chen, F. S., et al. (2005). Shoulder and elbow injuries in the skeletally immature athlete. *The Journal of the American Academy of Orthopaedic Surgeons*, 13:172-185; Fleisig, G. S., et al. (1996). Biomechanics of overhand throwing with implications for injury. *Sports Medicine*, 21:421-437; Werner, S. L., et al. (1993) Biomechanics of the elbow during baseball pitching. *Journal of Sports Physical Therapy*, 17:274-278.

FIGURE 5-29 (CONTINUED)

irritation and strain in this phase of the throw are found at the sites of the muscular attachment and in the subacromial area. This area is subjected to compression during adduction and internal rotation in this phase.

The last phase of throwing is the follow-through or deceleration phase. In this phase, the arm travels across the body in a diagonal movement and eventually stops over the opposite knee. This phase begins after the ball is released. In the early portion of this phase, after maximum internal rotation in the joint is achieved, a very quick muscular action takes place, resulting in external rotation and horizontal flexion of the arm. After this into the later stages of the follow-through are trunk rotation and replication of the shoulder and scapular movements of the cocking phase. This includes an increase in the activity of the deltoid as it attempts to slow the horizontally flexed arm; the latissimus dorsi as it creates further internal rotation; the trapezius, which creates slowing of the scapula; and the supraspinatus, to maintain the arm abduction and continue to produce internal rotation (37,55). There is also a very rapid increase in the activity of the biceps brachii and the brachialis in the follow-through phase as these muscles attempt to reduce the tensile loads on the rapidly extending forearm. In this phase of throwing, the posterior capsule and corresponding muscles and the biceps brachii (6) are at risk for injury because they are rapidly stretched.

THE GOLF SWING

The golf swing presents a more complicated picture of shoulder muscle function than throwing because the left and right arms must work in concert (Fig. 5-30). That is,

the arms produce opposite movements and use opposing muscles. In the backswing for a right-handed golfer, the club is brought up and back behind the body as the left arm comes across the body and the right arm abducts minimally (38). The shoulder's muscular activity in this phase is minimal except for moderate subscapularis activity on the target arm to produce internal rotation and marked activity from the supraspinatus on the trailing arm to abduct the arm (50,55). In the shoulder girdle, all parts of the trapezius of the trailing side work together with the levator scapula and rhomboid to elevate and adduct the scapula. On the target side, the serratus anterior protract the scapula.

In the forward swing, movement of the club is initiated by moderate activity from the latissimus dorsi and subscapularis muscles on the target side. On the trailing side, there is accompanying high activity from the pectoralis major, moderate activity from the latissimus dorsi and subscapularis, and minimal activity from the supraspinatus and deltoid. In the shoulder girdle, the trapezius, rhomboid, and levator scapula of the target arm are active as the scapula is adducted. The serratus anterior is also active in the trailing limb as the scapula is abducted. This phase brings the club around to shoulder level through continued internal rotation of the left arm and the initiation of internal rotation with some adduction of the right arm.

The acceleration phase begins when the arms are at approximately shoulder level and continues until the club makes contact with the ball. On the target side, there is substantial muscular activity in the pectoralis major, latissimus dorsi, and subscapularis as the arm is extended and maintained in internal rotation. On the trailing side, there is even greater activity from these same three muscles as the arm is brought vigorously downward (50,55).

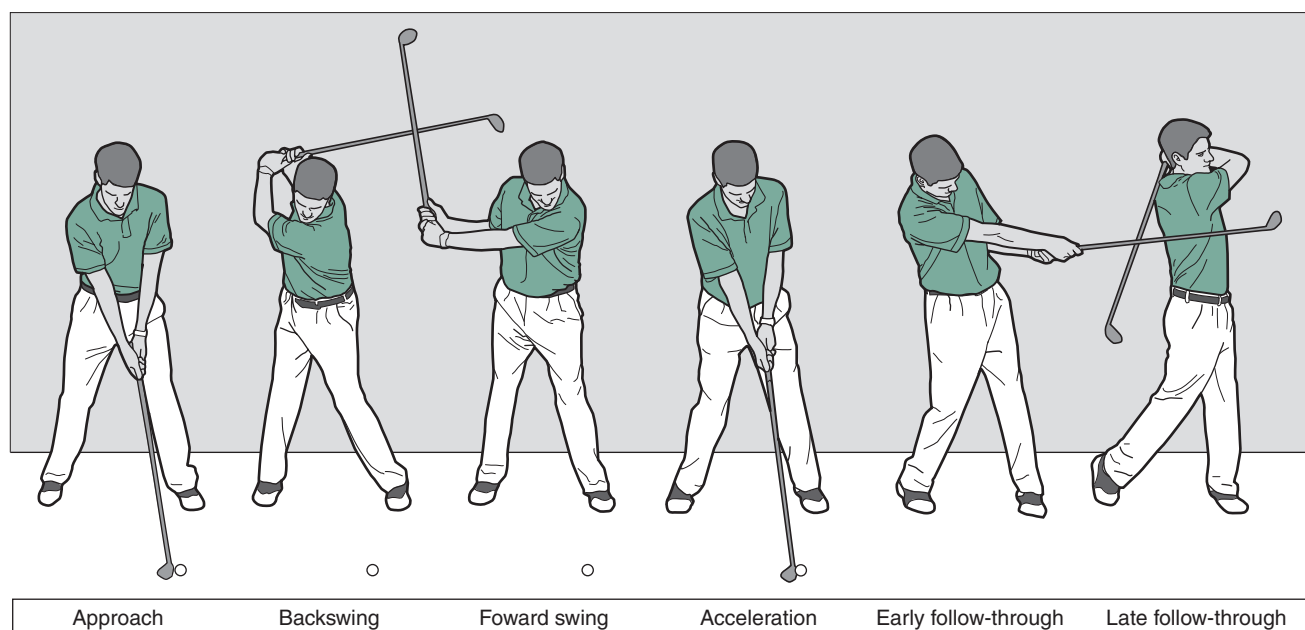
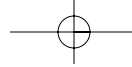


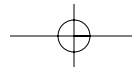
FIGURE 5-30 Upper extremity muscles used in the golf swing showing the level of muscle activity (low, moderate, high) and the type of muscle action (concentric [CON] and eccentric [ECC]).



Muscle	Back Swing: Ball Address to Top of Backswing			Forward Swing: Top of Swing to Club Horizontal (Early Part of Downswing)			Acceleration: Horizontal Club to Impact (Late Part of Downswing)			Early Follow-through: Impact to Horizontal Club			Late Follow-through: Horizontal to Completion of Swing		
	Level	Action	Purpose	Level	Action	Purpose	Level	Action	Purpose	Level	Action	Purpose	Level	Action	Purpose
Deltoid			Shoulder horizontal abduction on LEFT by posterior deltoid	Low	CON				Low	CON	Shoulder horizontal abduction on LEFT by posterior deltoid	Low	CON	Shoulder horizontal abduction on LEFT by posterior deltoid	
Infra-spinatus	Low	CON	Shoulder horizontal abduction and external rotation on RIGHT				Low	CON	Shoulder horizontal abduction and external rotation on LEFT			MOD- HIGH	CON	External rotation and horizontal abduction on LEFT	
Latissimus Dorsi			Shoulder adduction/ ext on left and right sides Shoulder internal rotation on RIGHT	MOD	CON		High	CON	Shoulder Adduction/ Extension on left and right sides			Low	ECC	Control of LEFT shoulder external rotation and abduction; control of RIGHT shoulder abduction	
Levator Scapulae	Low	CON	Scapular elevation RIGHT				High	CON	Scapular elevation on LEFT			Low	ECC	Control of scapular elevation on RIGHT	
Pectoralis Major	Low	CON	Shoulder internal rotation and horizontal adduction on LEFT	High	CON		High	CON	Internal shoulder rotation and horizontal adduction on RIGHT			High	CON	Internal shoulder rotation and horizontal adduction on RIGHT	
Rhomboids	Low	CON	Scapula adduction and upward rotation on RIGHT	High	CON		High	ECC	Controls arm horizontal abduction and external rotation on LEFT			High	ECC	Controls arm horizontal abduction and external rotation on LEFT	
Serratus Anterior	Low	CON	Scapula abduction on LEFT	MOD	CON		High	CON	Scapula abduction on RIGHT			High	CON	Scapula abduction on RIGHT	
Subscapularis	High	CON	Shoulder internal rotation on LEFT	Low	CON		High	CON	Shoulder internal rotation on RIGHT			MOD	ECC	Control of external rotation of LEFT	
Supraspinatus	Low	CON	Shoulder Abduction on RIGHT and LEFT												
Trapezius -Upper	MOD	CON	Scapular Upward Rotation and Elevation on RIGHT				High	CON	Scapular adduction on LEFT						
-Middle	MOD	CON	Scapular Upward Rotation and Elevation on RIGHT												
-Lower				MED	CON	Adduction of shoulder girdle LEFT	High	CON	Wrist Flexion on the right side just before contact with ball						
Wrist/Finger Flexors															

Sources: Jobe, F. W., et al. (1996). Rotator cuff function during a golf swing. *American Journal of Sports Medicine*, 14:388-392; McHardy, A. & Pollard, H. (2005). Muscle activity during the golf swing. *British Journal of Sports Medicine*, 39, 799-804; Moynes, D. R., et al. (1986). Electromyography and motion analysis of the upper extremity in sports. *Physical Therapy*, 66:1905-1910; Pink, M., et al. (1990). Electromyographic analysis of the shoulder during the golf swing. *The American Journal of Sports Medicine*, 18:137-140.

FIGURE 5-30 (CONTINUED)



As soon as contact with the ball is made, the follow-through phase begins with continued movement of the arm and club across the body to the target side. This action must be decelerated. In the follow-through phase, the target side has high activity in the subscapularis and moderate activity in the pectoralis major, latissimus dorsi, and infraspinatus as the upward movement of the arm is curtailed and slowed (55). It is here, in the follow-through phase, that considerable strain can be placed on the posterior portion of the trailing shoulder and the anterior portion of the target shoulder during the rapid deceleration.



External Forces and Moments Acting at Joints in the Upper Extremity

Muscle activity in the shoulder complex generates high forces in the shoulder joint itself. The rotator cuff muscle group as a whole, capable of generating a force 9.6 times the weight of the limb, generates maximum forces at 60° of abduction (89). Because each arm constitutes approximately 7% of body weight, the rotator cuff generates a force in the shoulder joint equal to approximately 70% of body weight. At 90° of abduction, the

deltoid generates a force averaging eight to nine times the weight of the limb, creating a force in the shoulder joint ranging from 40% to 50% of body weight (89). In fact, the forces in the shoulder joint at 90° of abduction have been shown to be close to 90% of body weight. These forces can be significantly reduced if the forearm is flexed to 90° at the elbow.

In throwing, compressive forces have been measured in the range of 500 to 1000 N (1,23,52,84) with anterior forces ranging from 300 to 400 N (52). In a tennis serve, forces at the shoulder have been recorded to be 423 N and 320 N in the compressive and mediolateral directions, respectively (60). As a comparison, lifting a block to head height has been shown to generate 52 N of force (57), and crutch and cane walking have generated forces at the shoulder of 49 and 225 N, respectively (7,31).

The load-carrying capacity of the elbow joint is also considerable. In a push-up, the peak axial forces on the elbow joint average 45% of body weight (2,18). These forces depend on hand position, with the force reduced to 42.7% of body weight with the hands farther apart than normal and increased to 65% of body weight in the one-handed push up (16). Radial head forces are greatest from 0° to 30° of flexion and are always higher in pronation. Joint forces at the ulnohumeral joint can range from 1 to 3 body weights (~750–2500 N) with strenuous lifting (24).

Sample upper extremity joint torques

Activity	Joint	Moments
Cane walking (7)	Shoulder	24.0 Nm
Lifting a 5-kg box from floor to shoulder height (7)	Shoulder	21.8 Nm
Lifting and walking with a 10-kg suitcase (7)	Shoulder	27.9 Nm
Lifting a block to head height (57)	Shoulder	14 Nm
	Elbow	5.8 Nm
Push-up (18)	Elbow	24.0 Nm
Rock climbing crimp grip (81)	Fingers (DIP)	26.4 Nm
Sit to stand (7)	Shoulder	16.2 Nm
Stand to sit (7)	Shoulder	12.3 Nm
Tennis serve (60)	Shoulder	94 Nm internal rotation torque
	Elbow	106 Nm varus torque
Follow-through phase of throwing (84)	Elbow	55 Nm flexion torque
Late cock phase of throwing (1,23,84)	Elbow	54–120 Nm of varus torque
Weight lifting (8)	Shoulder	32–50 Nm
Wheelchair propulsion (79)	Shoulder	50 Nm
Wheelchair propulsion (80)	Shoulder	7.2 Nm level propulsion (paraplegia) 14.6 Nm propulsion up slope (paraplegia)
	Elbow	3.0 Nm level propulsion (paraplegia) 5.7 Nm propulsion up slope (paraplegia)



Summary

The upper extremity is much more mobile than the lower extremity, even though the extremities have structural similarities. There are similarities in the connection into girdles, the number of segments, and the decreasing size of the bones toward the distal end of the extremities.

The shoulder complex consists of the sternoclavicular joint, the AC joint, and the glenohumeral joint. The sternoclavicular joint is very stable and allows the clavicle to move in elevation and depression, protraction and retraction, and rotation. The AC joint is a small joint that allows the scapula to protract and retract, elevate and depress, and rotate up and down. The glenohumeral joint provides movement of the humerus through flexion and extension, abduction and adduction, medial and lateral rotation, and combination movements of horizontal abduction and adduction and circumduction. A final articulation, the scapulothoracic joint, is called a *physiological joint* because of the lack of connection between two bones. It is here that the scapula moves on the thorax.

There is considerable movement of the arm at the shoulder joint. The arm can move through 180° of abduction, flexion, and rotation because of the interplay between movements occurring at all of the articulations. The timing of the movements between the arm, scapula, and clavicle is termed the *scapulohumeral rhythm*. Through 180° of elevation (flexion or abduction), there is approximately 2:1 degrees of humeral movement to scapular movement.

The muscles that create movement of the shoulder and shoulder girdle are also important for maintaining stability in the region. In abduction and flexion, for example, the deltoid produces about 50% of the muscular force for the movement, but it requires assistance from the rotator cuff (teres minor, subscapularis, infraspinatus, supraspinatus) to stabilize the head of the humerus so that elevation can occur. Also, the shoulder girdle muscles contribute as the serratus anterior and the trapezius assist to stabilize the scapula and produce accompanying movements of elevation, upward rotation, and protraction.

To extend the arm against resistance, the latissimus dorsi, teres major, and pectoralis major act on the humerus and are joined by the rhomboid and the pectoralis minor, which retract, depress, and downwardly rotate the scapula. Similar muscular contributions are made by the infraspinatus and teres minor in external rotation of the humerus and the subscapularis, latissimus dorsi, teres major, and pectoralis major in internal rotation.

The shoulder muscles can generate considerable force in adduction and extension. The next strongest movement is flexion, and the weakest movements are abduction and rotation. The muscles surrounding the shoulder joint are capable of generating high forces in the range of eight to nine times the weight of the limb.

Conditioning of the shoulder muscles is relatively easy because of the mobility of the joint. Numerous strength and flexibility exercises are used to isolate specific muscle groups and to replicate an upper extremity pattern used in a skill. Special exercise considerations for individuals with shoulder injuries should exclude exercises that create impingement in the joint.

Injury to the shoulder complex can be acute in the case of dislocations of the sternoclavicular or glenohumeral joints and fractures of the clavicle or humerus. Injuries can also be chronic, as with bursitis and tendinitis. Common injuries associated with impingement of the shoulder joint are subacromial bursitis, bicipital tendinitis, and tears in the supraspinatus muscle.

The elbow and the radioulnar joints assist the shoulder in applying force and placing the hand in a proper position for a desired action. The joints that make up the elbow joint are the ulnohumeral and radiohumeral joints, where flexion and extension occur, and the superior radioulnar joint, where pronation and supination of the forearm occur. The region is well supported by ligaments and the interosseous membrane running between the radius and the ulna. The joint structures allow approximately 145° to 160° of flexion and 70° to 85° of pronation and supination.

Twenty-four muscles span the elbow joint, and these can be further classified into flexors (biceps brachii, brachioradialis, brachialis, pronator teres, extensor carpi radialis), extensors (triceps brachii, anconeus), pronators (pronator quadratus, pronator teres), and supinators (biceps brachii, supinator). The flexor muscle group is considerably stronger than the extensor group. Maximum flexion strength can be developed from the semiprone forearm position. Extension strength is maximum in a flexion position of 90°. Pronation and supination strength is also maximum from the semiprone position.

The elbow and forearm are vulnerable to injury as a result of falling or repetitive overuse. In absorbing high forces, the elbow can dislocate or fracture or muscles can rupture. Through overuse, injuries such as medial or lateral tension syndrome can produce epicondylitis, tendinitis, or avulsion fractures.

The wrist and hand consist of complex structures that work together to provide fine movements used in a variety of daily activities. The main joints of the hand are the radiocarpal joint, inferior radioulnar joint, midcarpal and intercarpal joints, CMC joints, MCP joints, and IP joints. The hand is capable of moving through 70° to 90° of wrist flexion, 70° to 80° of extension, 15° to 20° of radial flexion, and 30° to 40° of ulnar flexion. The fingers can flex through 70° to 110°, depending on the actual joint of interest (MCP or IP), 20° to 30° of hyperextension, and 20° of abduction. The thumb has special structural and functional characteristics that are related to the role of the CMC joint.

The extrinsic muscles that act on the hand enter the region as tendons. The muscles work in groups to produce wrist flexion (flexor carpi ulnaris, flexor carpi radialis,

palmaris longus), extension (extensor carpi ulnaris, extensor carpi radialis longus, extensor carpi radialis brevis), ulnar flexion (flexor carpi ulnaris, extensor carpi ulnaris), and radial flexion (flexor carpi radialis, extensor carpi radialis longus, extensor carpi radialis brevis). Finger flexion is produced by the flexor digitorum profundus and flexor digitorum superficialis, and extension is produced primarily by the extensor digitorum. The fingers are abducted by the dorsal interossei and adducted by the palmar interossei.

Strength in the fingers is important in activities and sports in which a firm grip is essential. Grip strength can be enhanced by placing the thumb in a position parallel with the fingers (fist position). When precision is required, the thumb should be placed perpendicular to the fingers. The muscles of the hand can be exercised via a series of exercises that incorporates various wrist and finger positions.

The fingers and hand are frequently injured because of their vulnerability, especially when performing activities such as catching balls. Sprains, strains, fractures, and dislocations are common results of injuries sustained by the fingers or hands in the absorption of an external force. Other common injuries in the hand are associated with overuse, including medial or lateral tendinitis or epicondylitis and carpal tunnel syndrome.

The upper extremity muscles are very important contributors to specific sport skills and movements. In the push-up, for example, the pectoralis major, latissimus dorsi, and triceps brachii are important contributors. In swimming, the latissimus dorsi, teres major, pectoralis major, supraspinatus, infraspinatus, middle deltoid, and serratus anterior make important contributions. In throwing, the deltoid, supraspinatus, infraspinatus, teres minor, subscapularis, trapezius, rhomboid, latissimus dorsi, pectoralis major, teres major, and deltoid all contribute. In the forearm, the triceps brachii is an important contributor to rising from a chair, wheelchair activities, and throwing. Likewise, the biceps brachii and the pronator muscles are important in various phases of throwing.

The upper extremity is subject to a variety of loads, and loads as high as 90% of body weight can be applied to the shoulder joint as a result of muscle activity and other external forces. At the elbow, forces as high as 45% of body weight have been recorded. These forces are increased and decreased with changing joint positions and muscular activity.

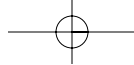
REVIEW QUESTIONS

True or False

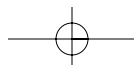
- ___ The triceps brachii is a stronger extensor at the elbow joint when the arm is flexed at the shoulder joint.
- ___ The anterior rotator cuff is most commonly injured in the follow-through phase of throwing.
- ___ The only point of skeletal attachment of the upper extremity to the trunk occurs at the sternoclavicular joint.
- ___ The brachialis muscle has a large cross-section and good mechanical advantage.
- ___ The flexor digitorum superficialis can flex each finger individually.
- ___ Abduction strength of the shoulder is twice that of adduction strength.
- ___ Posterior dislocations of the shoulder are rare.
- ___ Most of the motion in scapular range of motion occurs at the AC joint.
- ___ The glenoid fossa is only one quarter the size of the head of the humerus.
- ___ The shoulder joint capsule is very small, offering more support to the joint.
- ___ The deltoid generates about 50% of the muscle force for abduction or flexion.
- ___ External rotation is the weakest joint action in the shoulder.
- ___ The carrying angle at the elbow is higher in males.
- ___ The medial epicondyle is a site of injury because of tension in the wrist flexors.
- ___ Exercises such as the behind-the-neck pull-down should be avoided by people with anterior shoulder problems.
- ___ The biceps brachii is most effective as a flexor when the forearm is pronated.
- ___ The scaphoid transmits forces from the hands to the forearm.
- ___ When the hand flexes, movement starts at the radio-carpal joint.
- ___ The most flexion of the fingers occurs in the index finger.
- ___ The distal end of the radius is the most frequently fractured area of the body.
- ___ The pain in carpal tunnel syndrome is caused by nerve impingement.
- ___ A flexed wrist position is the optimal position for typing.
- ___ Peak forces acting on the elbow joint can be as high as 45% of body weight.
- ___ More range of motion in wrist extension can be achieved if the fingers are also extended.
- ___ Flexion at the shoulder joint is limited when the arm is externally rotated.

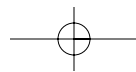
Multiple Choice

- The following muscles contribute to arm flexion:
 - deltoid
 - latissimus dorsi
 - teres minor
 - pectoralis minor
- The muscles that form the rotator cuff include:
 - deltoid, trapezius, pectoralis major, pectoralis minor
 - infraspinatus, pectoralis minor, subscapularis


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- c. teres minor, supraspinatus, subscapularis, infraspinatus
d. trapezius, subclavius, rhomboid
- 3.** The muscle that turns the palm downward is the:
a. supinator
b. extensor digitorum
c. pronator quadratus
d. flexor carpi ulnaris
- 4.** Which movements are possible at both the shoulder and elbow joint?
a. pronation and flexion
b. circumduction and flexion
c. extension and flexion
d. rotation and flexion
- 5.** Which pair of muscles would not be antagonistic to each other?
a. anterior deltoid and latissimus dorsi
b. biceps brachii and triceps brachii
c. rhomboid and subscapularis
d. deltoid and supraspinatus
- 6.** The function of the rotator cuff is to:
a. counter compressive forces generated by the deltoid during abduction
b. elevate shoulder
c. counter internal rotation forces generated by the latissimus dorsi
d. depress the scapula
- 7.** The biceps brachii can develop the most force:
a. when the forearm is pronated.
b. when the forearm is supinated.
c. when the forearm is in the neutral position.
d. when the shoulder is flexed.
- 8.** The rhomboid can:
a. elevate the scapula
b. downward rotate the scapula
c. adduct the scapula
d. All of above
e. None of above
- 9.** The motion(s) possible at the radioulnar joint is (are):
a. rotation
b. flexion and extension
c. pronation and supination
d. Both B and C
- 10.** Stability in the glenohumeral joint is derived primarily from the _____.
a. joint contact area
b. vacuum in the joint
c. ligaments and muscles
d. All of the above
- 11.** The muscle(s) responsible for horizontal adduction of the arm is (are):
a. latissimus dorsi
b. pectoralis major
c. teres minor
d. a and b
e. a and c
- 12.** The function of a bursa is to _____.
a. distribute load
b. maintain joint stability
c. reduce friction
d. All of the above
- 13.** The arm can abduct through
a. 60° to 90°
b. 90° to 110°
c. 120° to 150°
d. 150° to 180°
- 14.** The greatest strength output in the shoulder is generated in _____, and the weakest output is generated in _____.
a. extension, internal rotation
b. flexion, external rotation
c. adduction, external rotation
d. abduction, internal rotation
- 15.** If the arm is adducted against gravity, the action is _____, but if it is lowered against an external force, such as a weight machine, the action is _____.
a. eccentric, concentric
b. eccentric, eccentric
c. concentric, eccentric
d. concentric, concentric
- 16.** Impingement syndrome can involve an irritation of the
a. triceps brachii
b. biceps brachii
c. supraspinatus
d. Both A and C
e. Both B and C
- 17.** Persons with rotator cuff problems should avoid heavy lifting in the _____ movement.
a. flexion
b. extension
c. abduction
d. adduction
- 18.** Flexion of the middle and ring finger:
a. usually occurs together
b. can occur independently
c. occurs with finger abduction
d. is limited with the wrist flexed
- 19.** Approximately _____ of pronation and _____ of supination is required for daily living activities.
a. 90°, 75°
b. 75°, 90°
c. 25°, 25°
d. 50°, 50°
- 20.** In the hand there are _____ rows of carpals with _____ bones in each row.
a. 2, 4
b. 2, 3
c. 3, 4
d. 3, 2
- 21.** Most of the muscles acting at the wrist and fingers are considered _____.
a. concentric
b. eccentric
c. intrinsic
d. extrinsic
- 22.** Grip strength can be enhanced by:
a. abducting the fingers
b. radially flexing the wrist



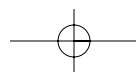
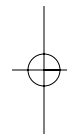
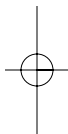


- c. extending the wrist
- d. pronating the forearm

- 23.** A Bennett's fracture is a common fracture to the:
- a. little finger
 - b. scaphoid
 - c. hamate
 - d. base of thumb
- 24.** The interosseus membrane:
- a. connects scaphoid to the radius
 - b. keeps the fingers from spreading
 - c. connects the radius and ulna
 - d. connects the radius and humerus
- 25.** The ratio of glenohumeral movement to scapular movement through 45° to 60° of abduction or flexion is:
- a. 2:1
 - b. 5:4
 - c. 1:3
 - d. 2:5

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GLOSSARY

- Abduction:** Sideways movement away from the midline or sagittal plane.
- Acromioclavicular Joint:** Articulation between the acromion process of the scapula and the lateral end of the clavicle.
- Adduction:** Sideways movement toward the midline or sagittal plane; return movement from abduction.
- Annular Ligament:** Ligament inserting on the anterior and posterior margins of the radial notch; supports the head of the radius.
- Bennett's Fracture:** Longitudinal fracture of the base of the first metacarpal.
- Bicipital Tendinitis:** Inflammation of the tendon of the biceps brachii.
- Boutonnière Deformity:** A stiff proximal interphalangeal articulation caused by injury to the finger extensor mechanism.
- Bursa:** A fibrous fluid-filled sac between bones and tendons or other structures that reduces friction during movement.
- Bursitis:** Inflammation of a bursa.
- Capitulum:** Eminence on the distal end of the lateral epicondyle of the humerus; articulates with the head of the radius at the elbow.
- Carpal Tunnel Syndrome:** Pressure and constriction of the median nerve caused by repetitive actions at the wrist.
- Carpometacarpal Joint:** Articulation between the carpals and the metacarpals in the hand.
- Carrying Angle:** Angle between the ulna and the humerus with the elbow extended; 10° to 25°.
- Clavicle:** An S-shaped long bone articulating with the scapula and the sternum.
- Coracoid Process:** A curved process arising from the upper neck of the scapula; overhangs the shoulder joint.
- Coronoid Fossa:** Cavity in the humerus that receives the coronoid process of the ulna during elbow flexion.
- Coronoid Process:** Wide eminence on proximal end of ulna; forms the anterior portion of the trochlear fossa.
- Degeneration:** Deterioration of tissue; a chemical change in the body tissue; change of tissue to a less functionally active form.
- Depression:** Movement of the segment downward (scapula, clavicle); return of the elevation movement.
- Dislocation:** Bone displacement; separation of the bony surfaces in a joint.
- Ectopic Bone:** Bone formation that is displaced away from the normal site.
- Ectopic Calcification:** Hardening of organic tissue through deposit of calcium salts in areas away from the normal sites.
- Elevation:** Movement of a segment upward (e.g., of the scapula, clavicle).
- Epicondylitis:** Inflammation of the epicondyle or tissues connecting to the epicondyle (e.g., medial or lateral epicondylitis).
- Force Couple:** Two forces, equal in magnitude, acting in opposite directions, that produce rotation about an axis.
- Fracture:** A break in a bone.
- Glenohumeral Joint:** The articulation between the head of the humerus and the glenoid fossa on the scapula.
- Glenoid Fossa:** Depression in the lateral superior scapula that forms the socket for the shoulder joint.
- Glenoid Labrum:** Ring of fibrocartilage around the rim of the glenoid fossa that deepens the socket in the shoulder and hip joints.
- Horizontal Extension (Abduction):** Movement of an elevated segment (arm, leg) away from the body in the posterior direction.
- Horizontal Flexion (Adduction):** Movement of an elevated segment (arm, leg) toward the body in the anterior direction.
- Hypothenar Eminence:** The ridge on the palm on the ulnar side created by the presence of intrinsic muscles acting on the little finger.
- Impingement Syndrome:** Irritation of structures above the shoulder joint due to repeated compression as the greater tuberosity is pushed up against the underside of the acromion process.

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- Intercarpal Joint:** Articulation between the carpal bones.
- Interosseous Membrane:** A thin layer of tissue running between two bones (radius and ulna, tibia and fibula).
- Interphalangeal Joint:** Articulation between the phalanx of the fingers and toes.
- Jersey Finger:** Avulsion of a finger flexor tendon through forced hyperextension.
- Lateral Epicondyle:** Projection from the lateral side of the distal end of the humerus giving attachment to the hand and finger extensors.
- Mallet Finger:** Avulsion injury to the finger extensor tendons at the distal phalanx; produced by a forced flexion.
- Medial Epicondyle:** Projection from the medial side of the distal end of the humerus giving attachment to the hand and finger flexors.
- Medial Tension Syndrome:** Also termed pitcher's elbow, medial pain brought on by excessive valgus forces that may cause ligament sprain, medial epicondylitis, tendinitis, or avulsion fractures to the medial epicondyle.
- Metacarpophalangeal Joint:** Articulation between the metacarpals and the phalanges in the hand.
- Midcarpal Joint:** Articulation between the proximal and distal row of carpals in the hand.
- Olecranon Bursitis:** Irritation of the olecranon bursae commonly caused by falling on the elbow.
- Olecranon Fossa:** A depression on the posterior distal humerus; creates a lodging space for the olecranon process of the ulna in forearm extension.
- Olecranon Process:** Projection on the proximal posterior ulna; fits into the olecranon fossa during forearm extension.
- Osteochondritis Dissecans:** Inflammation of bone and cartilage resulting in splitting of pieces of cartilage into the joint (shoulder, hip).
- Pitcher's Elbow:** Also termed medial tension syndrome, medial pain brought on by excessive valgus forces that may cause ligament sprain, medial epicondylitis, tendinitis, or avulsion fracture to the medial epicondyle.
- Power Grip:** A powerful hand position produced by flexing the fingers maximally around the object at all three finger joints and the thumb adducted in the same plane as the hand.
- Precision Grip:** A fine-movement hand position produced by positioning the fingers in a minimal amount of flexion with the thumb perpendicular to the hand.
- Pronation:** Inward rotation of a body segment (forearm).
- Protraction:** Also called abduction, movement of the scapula forward and away from the vertebral column.
- Radiocarpal Joint:** Articulation between the radius and the carpals (scaphoid and lunate).
- Radiohumeral Joint:** Articulation between the radius and the humerus.
- Radioulnar Joint:** Articulation between the radius and the ulna (superior and inferior).
- Retinaculum:** Fibrous band that contains tendons or other structures.
- Retraction:** Also called adduction, movement of the scapula backward and toward the vertebral column.
- Rotation:** Movement of a segment about an axis.
- Rotator Cuff:** Four muscles surrounding the shoulder joint, the infraspinatus, supraspinatus, teres minor, and subscapularis.
- Rupture:** An injury in which the tissue is torn or disrupted in a forcible manner.
- Scapulohumeral Rhythm:** The movement relationship between the humerus and the scapula during arm raising movements; the humerus moves 2° for every 1° of scapular movement through 180° of arm flexion or abduction.
- Scapula:** A flat, triangular bone on the upper posterior thorax.
- Scapulothoracic Joint:** A physiological joint between the scapula and the thorax.
- Shoulder Girdle:** An incomplete bony ring in the upper extremity formed by the two scapulae and clavicles.
- Sprain:** An injury to a ligament surrounding a joint; rupture of fibers of a ligament.
- Sternoclavicular Joint:** Articulation between the sternum and the clavicle.
- Strain:** Injury to the muscle, tendon, or muscle-tendon junction caused by overstretching or excessive tension applied to the muscle; tearing and rupture of the muscle or tendon fibers.
- Subacromial Bursae:** The bursae between the acromion process and the insertion of the supraspinatus muscle.
- Subacromial Bursitis:** Inflammation of the subacromial bursae that is common to impingement syndrome.
- Subluxation:** An incomplete or partial dislocation between two joint surfaces.
- Supination:** Outward rotation of a body segment (forearm).
- Tendinitis:** Inflammation of a tendon.
- Tenosynovitis:** Inflammation of the sheath surrounding a tendon.
- Thenar Eminence:** Ridge or mound on the radial side of the palm formed by the intrinsic muscles acting on the thumb.
- Traction Apophysitis:** Inflammation of the apophysis (process, tuberosity) created by a pulling force of tendons.
- Trigger Finger:** Snapping during flexion and extension of the fingers created by nodules on the tendons.
- Trochlea:** Medial portion of the distal end of the humerus; articulates with the trochlear notch of the ulna.
- Trochlear Notch:** A deep groove in the proximal end of the ulna; articulates with the trochlea of the humerus.
- Ulnohumeral Joint:** Articulation between the ulna and the humerus; commonly called the elbow.