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Functional Anatomy of the Shoulder

Glenn C. Terry, MD; Thomas M. Chopp, MD

The Hughston Clinic, Columbus, GA

Objective: Movements of the human shoulder represent the result of a complex dynamic interplay of structural bony anatomy and biomechanics, static ligamentous and tendinous restraints, and dynamic muscle forces. Injury to 1 or more of these components through overuse or acute trauma disrupts this complex interrelationship and places the shoulder at increased risk. A thorough understanding of the functional anatomy of the shoulder provides the clinician with a foundation for caring for athletes with shoulder injuries.

Data Sources: We searched MEDLINE for the years 1980 to 1999, using the key words "shoulder," "anatomy," "glenohumeral joint," "acromioclavicular joint," "sternoclavicular joint," "scapulothoracic joint," and "rotator cuff."

Data Synthesis: We examine human shoulder movement by breaking it down into its structural static and dynamic components. Bony anatomy, including the humerus, scapula, and clavicle, is described, along with the associated articulations, providing the clinician with the structural foundation for understanding how the static ligamentous and dynamic muscle forces exert their effects. Commonly encountered athletic injuries are discussed from an anatomical standpoint.

Conclusions/Recommendations: Shoulder injuries represent a significant proportion of athletic injuries seen by the medical provider. A functional understanding of the dynamic interplay of biomechanical forces around the shoulder girdle is necessary and allows for a more structured approach to the treatment of an athlete with a shoulder injury.

Key Words: anatomy, static, dynamic, stability, articulation

Movements of the human shoulder represent a complex dynamic relationship of many muscle forces, ligament constraints, and bony articulations. Static and dynamic stabilizers allow the shoulder the greatest range of motion of any joint in the body and position the hand and elbow in space. This extensive range of motion affords the athlete the ability to engage in a myriad of sports activities; however, this range of motion is not without risk. The bony architecture of the glenohumeral joint, with its large articulating humeral head and relatively small glenoid surface, relies heavily on ligamentous and muscular stabilizers throughout its motion arc (as opposed to the hip with its congruent "ball-in-socket" anatomy). If any of the static or dynamic stabilizers are injured by trauma or overuse, the shoulder is at increased risk for injury. Shoulder injuries account for 8% to 20% of athletic injuries.[1,2]

We examine the shoulder girdle from the standpoint of its component structures, namely the (1) bony anatomy (humerus, clavicle, scapula), (2) bony and muscular articulations (glenohumeral, acromioclavicular, sternoclavicular, and scapulothoracic), (3) static stabilizers (labrum, capsule, ligaments), and (4) muscles or dynamic stabilizers (rotator cuff, deltoid, and scapular stabilizers). Although these components will be discussed separately, they function to produce shoulder movement as a dynamic, interrelated unit. Understanding the functional anatomy and associated frequent sources of injury of the shoulder permits the sports medicine professional a more structured approach to the care of athletic shoulder injuries. The following material provides an overview of the functional components. The reader is encouraged to research further specific topics of interest.

Address correspondence to Glenn C. Terry, MD, The Hughston Clinic, 6262 Veterans Parkway, Columbus, GA 31909. E-mail address: gcterry@hughston.com

BONY ANATOMY

Humerus

The humerus is the largest and longest bone of the upper extremity, with its proximal portion consisting of the half-spheroid articulating surface or head, greater tuberosity, bicipital groove, lesser tuberosity, and proximal humeral shaft (Figure 1). The head is inclined relative to the shaft at the anatomical neck at an angle of 130° to 150° and is retroverted 26° to 31° from the medial and lateral epicondylar plane (Figure 2).[3] The greater tuberosity has 3 facets into which the tendons of the supraspinatus, infraspinatus, and teres minor insert. The lesser tuberosity is the site of insertion of the subscapularis, completing the rotator cuff. The facets provide for a continual ring insertion of the rotator cuff from posterior-inferior to anterior-inferior on the neck of the humerus. This insertion is interrupted only by the bicipital groove, through which the long head of the biceps brachii passes laterally and distally from its origin on the superior lip of the glenoid. Substantial forces applied to the shoulder (such as those seen in contact sports) often result in glenohumeral dislocation, with or without associated fracture of the proximal humerus. When fractures do occur, they commonly involve 1 or more of the tuberosities, which are then displaced in line with the force generated by the portion of the rotator cuff attached to that tuberosity. For example, a fracture of the greater tuberosity will be pulled superiorly and posteriorly secondary to the combined pulls of the supraspinatus, infraspinatus, and teres minor. The final fracture position is also influenced by the superior force on the humeral shaft by the deltoid and the medial force of the pectoralis major muscle.[4]

The surgical neck of the humerus is located just distal to the tuberosities at the level of the metaphyseal flare and is a common site of fractures in the elderly.[5] The incidence of

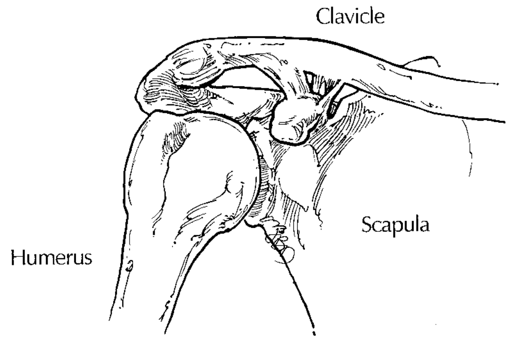

Figure 1. The 3 bones of the shoulder are the humerus, the clavicle, and the scapula.

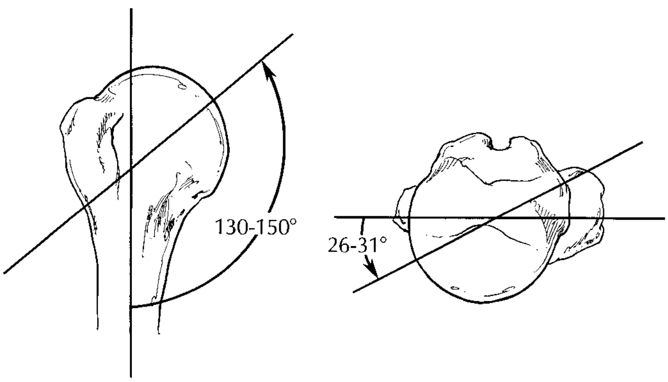

Figure 2. The humeral head:shaft angle is 130° to 150°; the head is retroverted 26° to 31°.

proximal humerus fractures increases with age over 40 years and is felt to be due to osteoporosis.[6] The surgical neck has also been implicated as a possible factor in glenohumeral dislocation through abutment on the acromion in extreme positions, such as hyperabduction.[7] In this case, the humeral head is levered inferiorly out of the glenoid fossa.[8]

Scapula

The scapula is a large, thin, triangular bone lying on the posterolateral aspect of the thorax, overlying ribs 2 through 7, that serves mainly as a site of muscle attachment. As a result of the protection of the overlying soft tissues, fractures occur through indirect trama to the processes (coracoid, spine, acromion, and glenoid).[9] The superior process, or spine, separates the supraspinatus muscle from the infraspinatus and extends superiorly and laterally to form the base of the acromion. The spine functions as part of the insertion of the trapezius muscle, as well as the origin of the posterior deltoid muscle. The acromion serves as a lever arm for function of the deltoid and articulates with the distal end of the clavicle, forming the acromioclavicular joint. The acromion forms a portion of the roof of the space for the rotator cuff, and variations in acromial shape can affect contact and wear on the cuff (impingement).[10] Tendinitis and bursitis are the result of impingement of the humeral head and overlying rotator cuff against the coracoacromial arch, which is composed of the acromion, coracoacromial ligament, and coracoid process. Impingement is often seen in overhead athletes who perform repetitive motions.

The coracoid process projects anteriorly and laterally from the upper border of the head of the scapula. The superior surface serves as the origin of the 2 coracoclavicular ligaments that are torn, along with the acromioclavicular ligament, in acromioclavicular (AC) joint separations. The most common cause of injury is a fall onto the point of the shoulder, as in football. The coracoid tip serves as the origin of the coracobrachialis muscle and the short head of the biceps brachii, as well as the insertion of the pectoralis minor muscle. The coracohumeral and coracoacromial ligaments originate on the coracoid as well. The scapular notch lies just medial to the base of the coracoid and is spanned by the transverse scapular ligament. The suprascapular nerve passes beneath the ligament to innervate the supraspinatus and infraspinatus muscles.[11,12]

The glenoid fossa, or cavity, represents the bony articulating surface for the humerus. Its articular surface is only one third to one fourth that of the humeral head (Figure 3), and hence, provides only a small contribution to glenohumeral stability. The glenoid surface is retroverted on average 4° to 12° with respect to the scapular plane.[13] The scapular plane lies 30° to 45° anterior with respect to the coronal plane of the body and, thus, articulates with the retroverted humeral head.[14] This orientation of the scapula to the coronal plane of the body and humeral head provides the bony foundation for the extensive normal range of shoulder motion.

Clavicle

The clavicle serves as the sole bony strut connecting the trunk to the shoulder girdle via the sternoclavicular joint medially and the acromioclavicular joint laterally. The clavicle has a double curve along its long axis and is subcutaneous in its full extent. The flat outer third serves as an attachment point for muscles and ligaments, whereas the tubular medial third accepts axial loading. The middle-third transitional zone is the thinnest portion and is a weak area mechanically, which may be 1 reason for the predominance of fractures in this area.[15] The clavicle serves as a site for muscle attachments, a barrier to protect underlying neurovascular structures, and a strut to stabilize the shoulder complex and prevent it from displacing medially with activation of the pectoralis and other axiohum-

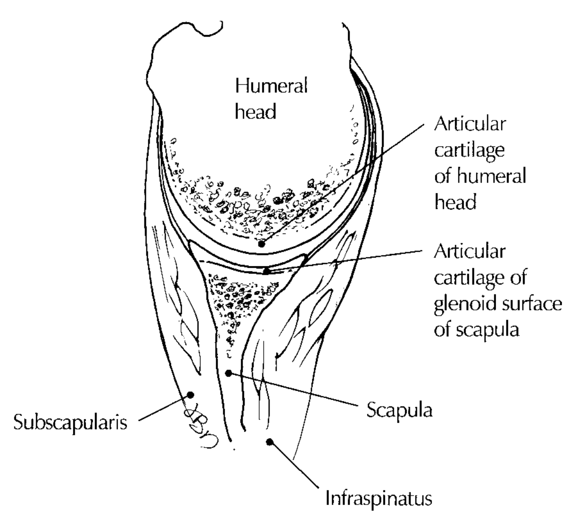

Figure 3. Note the large humeral head and the small glenoid articular surface. The glenoid articular cartilage is thicker at the periphery, and the humeral head is thicker at the center.

eral muscles.[16] Additionally, the clavicle prevents inferior migration of the shoulder girdle through the strong coracoclavicular ligaments. In high-grade AC joint separations, when this stability is lost, the shoulder girdle displaces inferiorly away from the clavicle.[8] As a result, on physical examination, the distal clavicle appears to displace superiorly.

JOINT ARTICULATIONS

Glenohumeral Joint

The glenohumeral joint is suited for extreme mobility with its mismatched large humeral head and small glenoid articular surface. At any given time, only 25% to 30% of the humeral head is in contact with the glenoid fossa.[17] However, despite this lack of articulating surface coverage, the normal shoulder precisely constrains the humeral head to within 1 to 2 mm of the center of the glenoid cavity throughout most of the arc of motion.[18–20] This precise constraint of the center of rotation through a large arc of motion is the result of an interplay of static (no active energy required, ie, capsule, labrum, ligaments) and dynamic (muscle) forces. The stabilizing effect of the articular surfaces and capsulolabral ligamentous complex is magnified by muscle forces, which produces a concavity-compression effect directed toward the glenoid center.[21] Biomechanical dysfunction from injury to the bony anatomy, static capsulolabral ligamentous structures, or dynamic muscle stabilizers through a single traumatic event or a series of repetitive microtrauma results in loss of this precise constraint of the center of rotation, or instability. Depending on the injured structures involved, the direction of instability may be primarily anterior, inferior, or posterior, or a combination of these. The degree of instability may range from mild subluxation to dislocation, with associated injury to the bony or capsulolabral structures, or both, and surrounding musculature. Treatment of instability in the athlete is aimed at surgically restoring the structural integrity of the injured capsulolabral ligamentous complex, followed by rehabilitation of the dynamic stabilizers. Restoration of normal glenohumeral biomechanics through reestablishment of the dynamic interplay of bony, static, and dynamic stabilizers is the final goal. If any of the components contributing to stability are not fully repaired or rehabilitated, the athlete will fail to return to the preinjury level of performance.

Passive Mechanisms

Articular Surface. The bony radius of the curvature of the glenoid is slightly flattened with respect to the humeral head. However, the glenoid articular cartilage is thicker at the periphery, thus creating significant articular surface conformity and resultant stability.[22] This resultant articular conformity additionally provides the foundation for the concavity-compression effect provided by the rotator cuff and surrounding musculature. The normal glenohumeral joint is fully sealed by the capsule and normally contains less than 1 mL of joint fluid under slightly negative intra-articular pressure, which provides a suction effect to resist humeral head translation, thereby increasing stability. In addition, adhesion and cohesion forces are created when fluid separates 2 closely opposing surfaces and, thus, the surfaces cannot be pulled apart easily (an example is 2 wet microscopic slides placed together).[23] The contribution of these factors in stability are probably minor and functional only at low loads.[24]

Glenoid Labrum. The glenoid labrum is a dense, fibrous structure, which is triangular on cross-section.[25] Located at the glenoid margin, the labrum serves to extend the conforming articular surfaces, thereby increasing contact surface area and adding to stability. The labrum also enhances stability by deepening the concavity of the glenoid socket, an average of 9 mm and 5 mm in the superoinferior and anteroposterior planes, respectively,[26] and loss of the integrity of the labrum (through injury) decreases resistance to translation by 20%.[21] The labrum also acts as an anchor point for the capsuloligamentous structures.[27] Bankart[28] deemed the detachment of the labrum from the anterior-inferior glenoid rim the “essential lesion” responsible for the high incidence of recurrent anterior dislocations. In this case, the labrum detaches traumatically along with the anchoring point of the inferior and middle glenohumeral ligaments. Also disrupted is the deepening effect of the labrum. Treatment is aimed at surgically restoring the functional integrity of the labrum and capsuloligamentous anchor. Pagnani et al[29,30] demonstrated the importance of superior labrum and biceps tendon injuries, noting increased anteroposterior and superoinferior translations in the lower and middle ranges of elevation.

Joint Capsule. The surface area of the capsule is approximately twice that of the humeral head, allowing for extensive range of motion. The capsule is truncated in shape, and the inferior portion, or axillary pouch, is redundant. The capsule tightens or “winds up” in various extremes of position; for example, the inferior pouch tightens in extreme abduction and external rotation, serving to stabilize the joint (Figure 4).[31] Although the capsule and glenohumeral ligaments are often described separately, they are intimately adherent anatomically. The capsuloligamentous structures reciprocally tighten and loosen during rotation of the arm to limit translation. In the midrange of motion, these structures are relatively lax, and stability is mainly provided by the actions of the rotator cuff and biceps through the concavity-compression effect.[21] At the extremes of motion, the ligaments tighten and become functional; they are especially important in providing stabilization when all other stabilizing mechanisms are overwhelmed.[8]

Ligaments. The coracohumeral ligament is a thick band of capsular tissue originating from the base of the lateral coracoid and inserting into the lesser and greater tuberosities. This ligament is taut with the arm in the adducted position and constrains the humeral head on the glenoid.[32] Additionally, the coracohumeral ligament and superior glenohumeral ligament stabilize the humeral head from inferior translation in adduction and from posterior translation in forward flexion, adduction, and internal rotation.[33]

The superior glenohumeral ligament extends from the anterosuperior edge of the glenoid to the top of the lesser tuberosity (Figure 5). It parallels the course of the coracohumeral ligament, and these 2 structures are considered similar in function. Together they constitute the rotator interval region between the anterior border of the supraspinatus and the superior border of the subscapularis.[34,35]

The middle glenohumeral ligament is the most variable of the 3 glenohumeral ligaments, being absent in 8% to 30% of patients. It originates from the supraglenoid tubercle, superior labrum, or scapular neck and inserts on the medial aspect of the lesser tuberosity. Its function is to limit anterior translation of

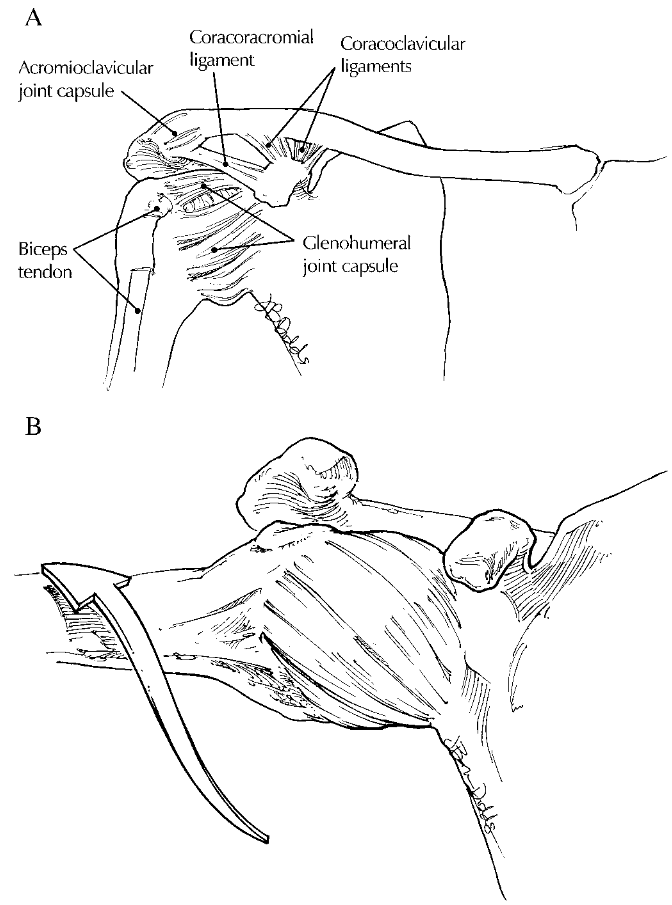

Figure 4. A, Ligaments of the shoulder joint. B, The capsule tightens in extreme abduction and external rotation, taking up the redundant capsule.

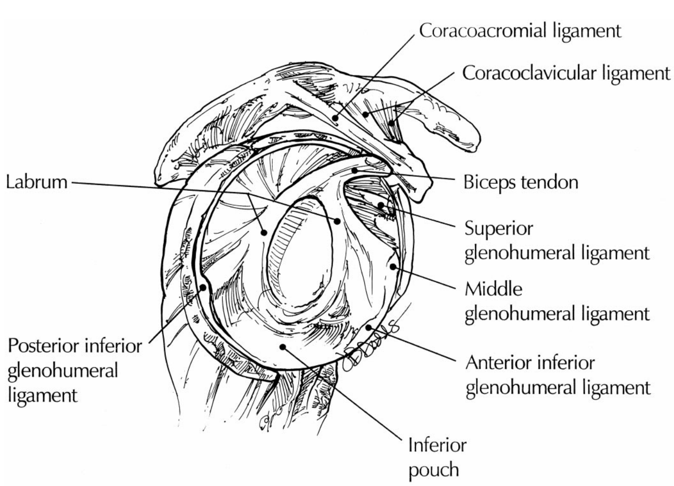

Figure 5. Cross-sectional view of the glenohumeral joint (with the humeral head removed) showing the glenohumeral ligaments and associated structures.

the humeral head in the lower ranges of abduction (60° to 90°) and inferior translation in the adducted position at the side.[36]

The inferior glenohumeral ligament is the thickest and most consistent of the 3 glenohumeral ligaments. It is often described as a complex containing an anterior band, axillary pouch, and posterior band. The anterior band extends from the anteroinferior labrum and glenoid lip to the lesser tuberosity of the humerus and is the thickest portion and the primary stabilizer against anterior translation of the humeral head in the throwing position of abduction and external rotation.[31,36] In this position, the complex moves anteriorly and becomes a barrier to anterior translation. Injury to the inferior glenohumeral ligament through repetitive microtrauma (as in pitching) or a single traumatic episode (dislocation) plays an integral role in recurrent instability. As noted above, treatment is aimed at surgically restoring the functional integrity of the inferior glenohumeral ligamentous complex.

Dynamic Stabilizers

Rotator Cuff Muscles. The rotator cuff is a group of muscles consisting of the subscapularis, supraspinatus, infraspinatus, and teres minor, which act as a dynamic steering mechanism for the humeral head (Figure 6). Three-dimensional movements or rotations of the humeral head are the result of the dynamic interplay between the muscles comprising the rotator cuff and the static stabilizers. Rotator cuff activation results in humeral head rotation and depression in positions of abduction. As a group, the rotator cuff muscles are smaller in cross-sectional area and size when compared with the larger, more superficial muscles such as the deltoid, pectoralis major, latissimus dorsi, and trapezius. Also, because they lie much closer to the center of rotation on which they act, their lever arm is shorter, and a smaller generated force results. Given this anatomical location, the rotator cuff is very well situated to provide stability to a dynamic fulcrum during glenohumeral abduction (Figure 7A).

Contraction of the rotator cuff results in concavity-compression, and asymmetric contraction acts to cause humeral head rotation or "steering" during shoulder motion. Additionally, force couples occur at the glenohumeral joint in multiple planes (Figures 7B, 7C). Force couples occur when the resultant force of 2 opposing muscle groups achieves a given moment. Inman et al[37] described the cephalad force of the deltoid counteracted by the inferior, or depressing, force of the subscapularis, infraspinatus, and teres minor.

The supraspinatus originates from the supraspinous fossa to insert forward and laterally at the superior aspect of the greater tuberosity. The tendon blends into the joint capsule and infraspinatus tendon below. The supraspinatus stabilizes the

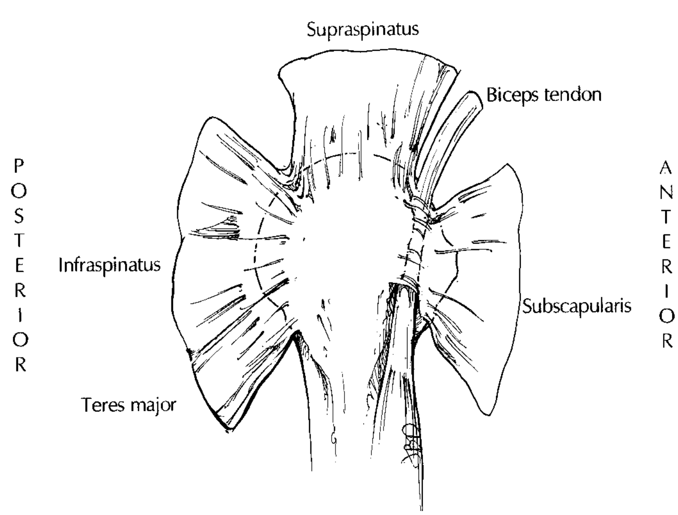

Figure 6. Sites of origin for the rotator cuff muscles.

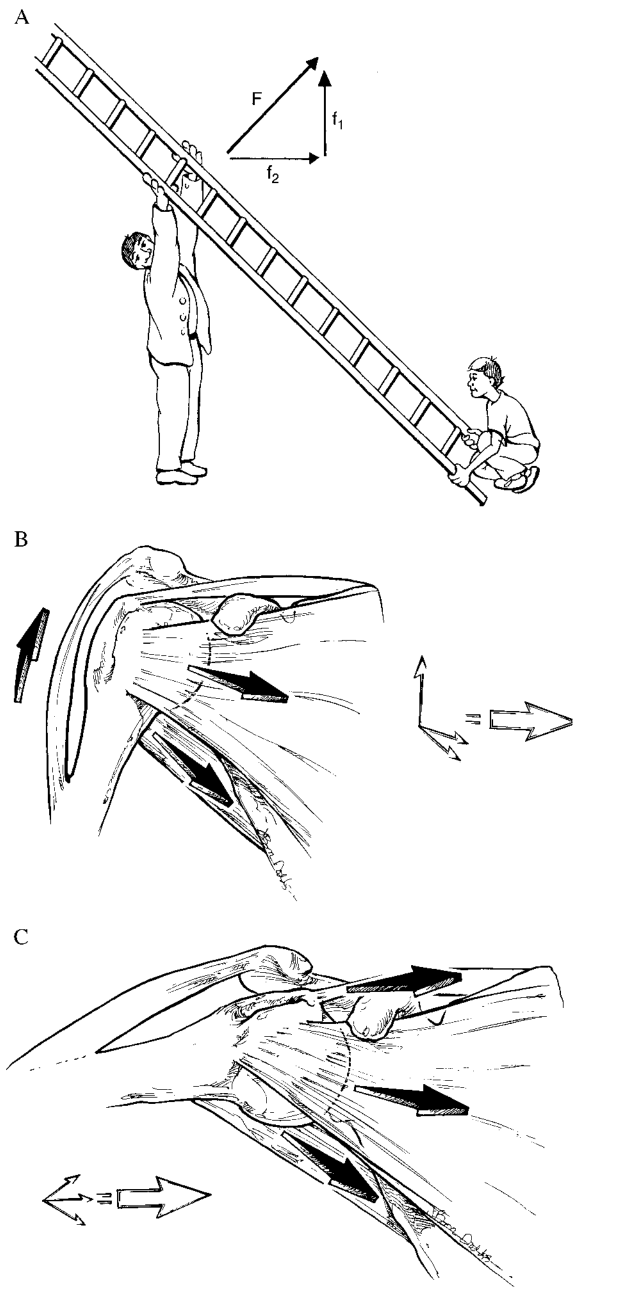

Figure 7. A, The muscles about the shoulder can be thought of as primary movers and primary stabilizers. This situation is somewhat analogous to that of a large man and small boy teaming up to raise a long, heavy ladder. Typically the stronger one will lift (move) the ladder while the weaker one will hold it from sliding or lifting off the ground (stabilize it). There comes a point at which the force generated by the stronger one can overpower the resistance of the weaker one and stability is lost. (Reprinted with permission from O'Driscoll SW. Atraumatic instability: pathology and pathogenesis. In: Matsen FA, Fu FH, Hawkins RJ, eds. *The Shoulder: A Balance of Mobility and Stability*. Rosemont, IL: American Academy of Orthopaedic Surgeons; 1993:307.) B, Force couple in the adducted position. C, Force couple in the abducted position.

glenohumeral joint and serves, along with the deltoid, to elevate the arm. Innervation is from the suprascapular nerve.

The infraspinatus originates from the infraspinous fossa and extends laterally to its tendinous insertion on the middle facet of the greater tuberosity. The infraspinatus, along with the teres minor, provides the primary external rotation force and also stabilizes the glenohumeral joint against posterior subluxation. Innervation is from the suprascapular nerve.

The teres minor originates from the mid to upper regions of the axillary border of the scapula and extends laterally and superiorly to its insertion on the most inferior facet of the greater tuberosity. In concert with the infraspinatus, the teres minor is an external rotator and glenohumeral stabilizer. Innervation is from the axillary nerve.

The subscapularis muscle comprises the anterior portion of the rotator cuff. It originates from the subscapular fossa to extend laterally to its insertion on the lesser tuberosity of the humerus. The tendon of the subscapularis is intimately associated with the anterior capsule. The axillary nerve passes along the inferior border of the scapula and is, therefore, subject to trauma from anterior dislocation. The subscapularis functions as an internal rotator, especially in maximum internal rotation. Innervation is from the upper and lower subscapular nerves.

The long head of the biceps must also be considered here, because it functions intimately with the rotator cuff as a humeral head depressor. Rodosky et al[38] have noted that contraction of the long head of the biceps during the late cocking phase of throwing can significantly reduce anterior translation and increase torsional rigidity of the joint resisting external rotation. Pagnani et al[29] also noted that in lower elevated positions, the long head of the biceps stabilized the joint anteriorly when the arm was internally rotated and stabilized the joint posteriorly when the arm was externally rotated. Injuries to the long head of the biceps and superior labrum may result from an excessively strenuous throwing program and produce loss of stability, decreased performance, and increasing symptoms.

Acromioclavicular Joint

The acromioclavicular joint is a diarthrodial joint between the lateral border of the clavicle and the medial edge of the acromion. The average joint size in the adult is 9×19 mm, and the joint is covered by a capsule. Because of the high axial loads transferred through this small surface area, contact stresses on the articular surface are high and may result in early failure, such as osteolysis in weight lifters or osteoarthritis. Stability of the acromioclavicular joint is provided mainly through the static stabilizers composed of the capsule, intra-articular disc, and ligaments.[39]

The capsule, which is thicker superiorly and anteriorly, surrounds the joint. It is reinforced by the acromioclavicular ligaments superiorly, inferiorly, posteriorly, and anteriorly. The fibers of the superior acromioclavicular ligament are the strongest and blend with the fibers of the deltoid and trapezius muscles. The intra-articular fibrocartilaginous disc occurs in 2 forms: partial and complete. The disc varies substantially in size and shape. It undergoes rapid degeneration (perhaps as a result of the high contact stress loads) and is functionally absent by the fourth decade.[39]

Additional stability of the acromioclavicular joint is derived through the coracoclavicular ligaments, which serve as the primary suspensory ligaments of the upper extremity. Two distinct ligaments, the trapezoid and conoid, span the distance from the superior surface of the coracoid to insert on the trapezoid ridge and conoid tuberosity of the clavicle, respectively. These stout ligaments suspend the shoulder girdle from the clavicle at an average distance of 13 mm. The acromioclavicular ligaments are the primary restraint to AC joint posterior translation, while the coracoclavicular ligaments are the primary restraint to vertical displacement. The common AC separation injury represents gradations of injury level, first to the acromioclavicular joint and then to the coracoclavicular ligaments, and is usually the result of an inferiorly directed force to the superior aspect of the shoulder (such as a fall onto the point of the shoulder).[8]

Sternoclavicular Joint

The sternoclavicular joint represents the only true articulation between the upper extremity and the axial skeleton (Figure 8). It is a sellar (saddle) joint formed by the articulation of the medial end of the clavicle and the upper portion of the sternum. Given the great disparity in size between the large bulbous end of the clavicle and the smaller articular surface of the sternum, stability is provided by the surrounding ligamentous structures.

The intra-articular disc-ligament is a dense, fibrous structure arising from the junction of the first rib, passing through the sternoclavicular joint, and attaching to the superior and medial clavicle. This disc-ligament acts as a checkrein against medial displacement of the inner clavicle.

The costoclavicular ligament arises from the upper surface of the first rib to attach to the inferior surface of the medial clavicle. Bearn[40] has shown experimentally that the anterior fibers resist excessive upward rotation and the posterior fibers resist excessive downward rotation. The interclavicular ligament connects the superomedial aspect of the clavicle with the capsular ligaments and upper sternum. This ligament acts as a checkrein against excessive downward rotation of the clavicle. The capsular ligament covers the anterosuperior and posterior aspects of the sternoclavicular joint. The anterior portion is heavier and stronger than the posterior portion and is the primary stabilizer against upward displacement of the inner clavicle caused by a downward force on the distal end of the shoulder.[40] Under normal circumstances, the sternoclavicular joint is capable of 30° to 35° of upward elevation, 35° of combined forward and backward movement, and 45° to 50° of rotation around its long axis.[41]

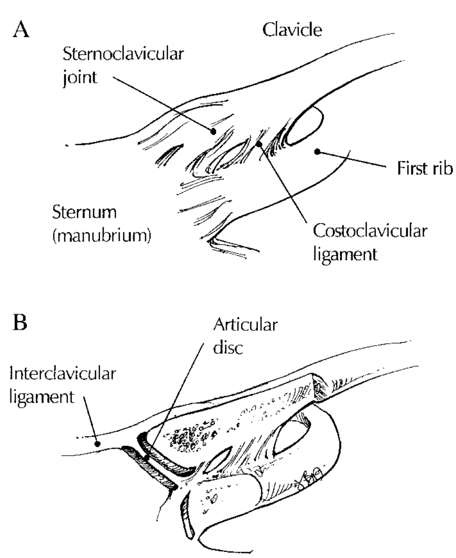

Figure 8. A, Anterior, and B, cross-sectional views of the sternoclavicular joint.

Scapulothoracic Articulation

Not a true joint, the scapulothoracic articulation represents a space between the convex surface of the posterior thoracic cage and the concave surface of the anterior scapula. It is occupied by neurovascular, muscular, and bursal structures that allow a relatively smooth motion of the scapula on the underlying thorax. With the scapula serving as the bony foundation of the shoulder girdle, the scapulothoracic articulation allows increased shoulder movement beyond the 120° offered solely by the glenohumeral joint. On average, there are approximately 2° of glenohumeral elevation for every 1° of scapulothoracic elevation, although the actual ratio can vary for any portion of the arc of motion.[42]

Seventeen muscles attach to or originate from the scapula and function to stabilize the scapula and provide motion. Among these, the most important are the serratus anterior, which maintains the medial angle against the chest wall, and the trapezius, which helps to rotate and elevate the scapula synchronously with glenohumeral motion (Figure 9). Rehabilitation of the overhead or throwing athlete must include the scapular-stabilizing musculature for optimal results.

Three bursae surround the scapula: 1 at the superomedial angle between the serratus anterior and the subscapularis, another between the serratus anterior and the lateral chest wall,

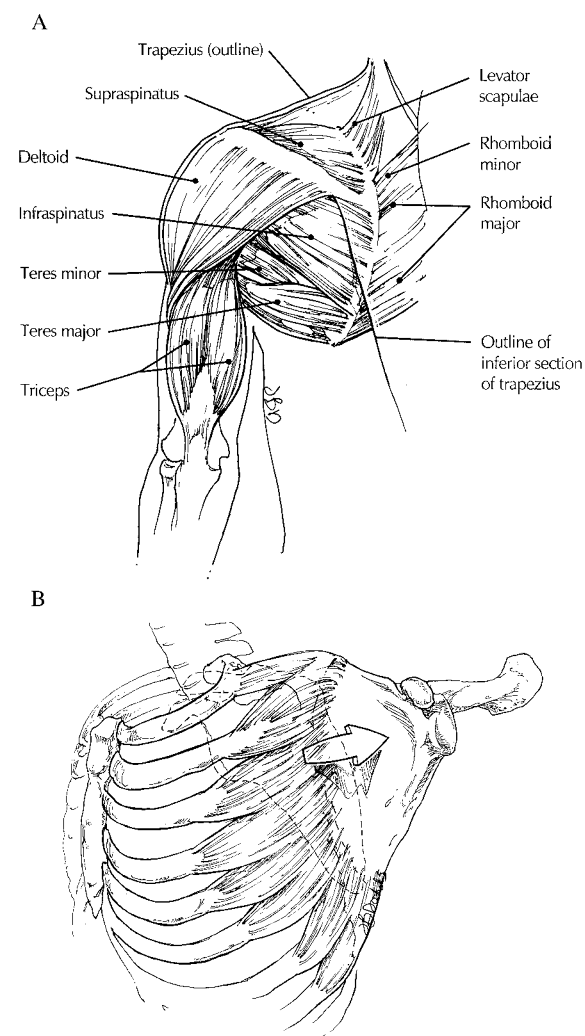

Figure 9. A, The scapulothoracic muscles, including B, the serratus anterior.

and the third at the inferior angle. All 3 have been associated with scapulothoracic bursitis and "snapping" scapula.[43]

Scapulothoracic Muscles

The trapezius has an extensive origin from the base of the skull to the upper lumbar vertebrae and inserts on the lateral aspect of the clavicle, acromion, and scapular spine. It functions mainly as a scapular retractor and elevator of the lateral angle of the scapula. It is innervated by the spinal accessory nerve.

The rhomboids, consisting of the major and minor muscles, originate from the spinous processes of C7 and T1 and T2 to T5, respectively. They insert on the medial aspect of the scapula and retract and elevate the scapula. The dorsal scapular nerve innervates the rhomboids.

The levator scapulae originates on the transverse processes of the cervical spine and inserts on the superior angle of the scapula. The levator scapule elevates the superior angle, resulting in upward and medial rotation of the scapular body. Innervation is from the third and fourth cervical spinal nerves.

The serratus anterior takes origin from the bodies of the first 9 ribs and the anterolateral aspect of the thorax and inserts through 3 portions from the superior to the inferior angle of the scapula. Activation of the serratus anterior causes scapular protraction and upward rotation. Innervation is by the long thoracic nerve, and nerve injuries here often manifest as a winged scapula.[43]

The pectoralis minor originates from the anterior portion of the second through fifth ribs and inserts on the base of the coracoid. It protracts and rotates the scapula inferiorly. Innervation is from the medial pectoral nerve.

The deltoid muscle consists of 3 portions: an anterior portion originating from the lateral clavicle, a middle portion originating from the acromion, and a posterior portion originating from the spinous process of the scapula. All 3 portions converge distally to insert on the deltoid tuberosity of the humerus. The anterior and middle portions allow for elevation in the scapular plane and assist in forward elevation with help from the pectoralis major and biceps. Innervation is by the axillary nerve.[43] As noted above, the deltoid acts in the force couples occurring at the glenohumeral joint.

Other Shoulder Muscles

The latissimus dorsi is a large triangular muscle arising from the spines of the lower 6 thoracic vertebrae and thoracolumbar fascia, through which it is attached to the lumbar and sacral vertebrae and to the supraspinous ligaments and posterior iliac crest. It converges from its wide origin to pass laterally around the lower border of the teres major, attaching to the intertubercular groove of the humerus. It functions to adduct, extend, and internally rotate the humerus. Innervation is by the thoracodorsal nerve from the posterior cord of the brachial plexus.

The teres major originates at the inferior angle of the scapula and rotates 180° toward its insertion into the medial lip of the intertubercular groove of the humerus. Its tendinous insertion blends with the insertion of the latissimus dorsi. It is primarily an internal rotator and adductor of the shoulder and extender of the arm. Innervation is from the lower subscapular nerve.

The coracobrachialis originates from the coracoid process and inserts on the anteromedial aspect of the humerus. Along with the short head of the biceps, the coracobrachialis flexes and adducts the glenohumeral joint. Innervation is from the musculocutaneous nerve.

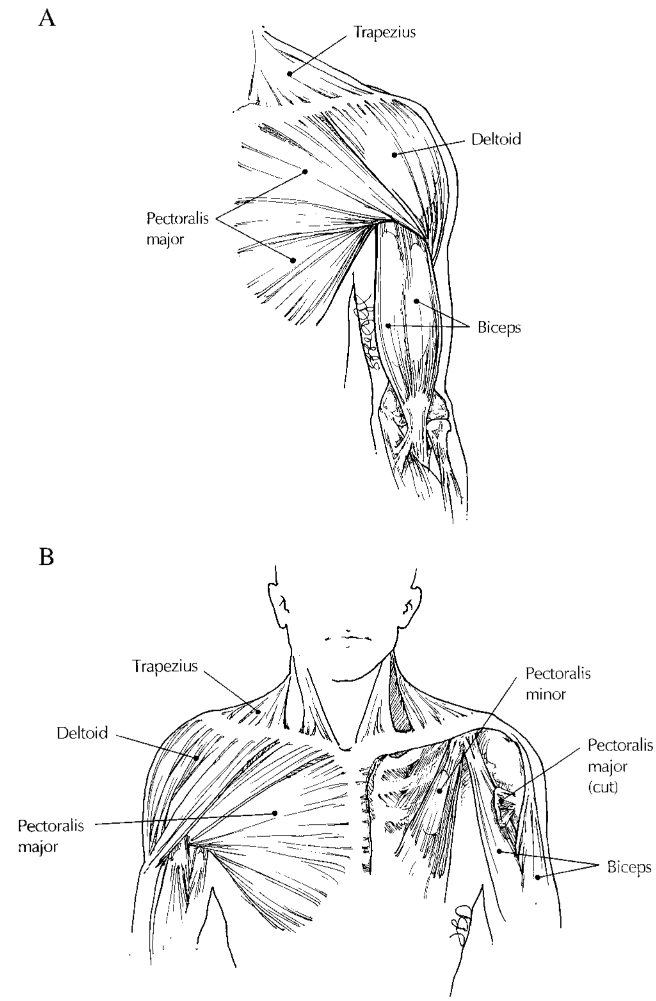

Figure 10. Other muscles of the shoulder. A, Note the pectoralis major and the deltoid, and B, the pectoralis minor and the 2 heads of the biceps.

The pectoralis major originates medially from the medial aspect of the clavicle, the sternum, and the fifth and sixth ribs (Figure 10). The muscle extends laterally to insert on the lateral lip of the bicipital groove. The muscle primarily functions in adduction and internal rotation of the humerus. Innervation is by the lateral and medial pectoral nerves.

The biceps has 2 heads. The long head originates from the supraglenoid tuberosity and superior labrum; the short head originates from the coracoid, along with the coracobrachialis and pectoralis minor. The biceps then extends distally to insert in the bicipital tuberosity of the radius. The long head of the biceps is located in the rotator interval between the supraspinatus and subscapularis tendons and serves as a primary head depressor during abduction. Innervation is from the musculocutaneous nerve.

SUMMARY

Shoulder motion is the result of the complex interplay of static and dynamic stabilizers. All 4 joints of the shoulder (glenohumeral, acromioclavicular, sternoclavicular, and scapulothoracic) must have free movement as a prerequisite. The bony anatomy provides the structural foundation from which the forces are generated and subsequently acted on. With regard to the glenohumeral joint, the capsuloligamentous complex provides static restraint, while the rotator cuff muscles (along with their respective force-couple antagonists) guide, steer, and maintain the head dynamically in the glenoid fossa. Glenohumeral injury and instability can result when 1 or more of the bony, static, or dynamic components of this interaction are disrupted. Additionally, when injury involves structures other than the glenohumeral joint specifically, the effects may be noted secondarily through decreased shoulder performance. Only when all the components contributing to shoulder motion are returned to their fully functional state can the athlete perform to the highest expectations. A thorough knowledge of the functional anatomy of the shoulder allows the medical provider to take a sound approach in the evaluation and management of the athlete's shoulder.

REFERENCES

1. Powell JW, Barber-Foss KD. Injury patterns in selected high school sports: a review of the 1995–1997 seasons. *J Athl Train.* 1999;34:277–284.
2. Steinbruck K. Epidemiology of sports injuries: 25-year analysis of sports orthopedic-traumatologic ambulatory care. *Sportverletz Sportschaden.* 1999;13:38–52.
3. Kronberg M, Brostrom LA, Soderlund V. Retroversion of the humeral head in the normal shoulder and its relationship to the normal range of motion. *Clin Orthop.* 1990;253:113–117.
4. Bigliani LU, Craig EV, Butters KP. Fractures of the shoulder, part I: fractures of the proximal humerus. In: Rockwood CA Jr, Green DP, Bucholz RW, eds. *Rockwood and Green's Fractures in Adults*. Vol 1. 3rd ed. Philadelphia, PA: JB Lippincott; 1991:871–927.
5. Hall MC, Rosser M. The structure of the upper end of the humerus with reference to osteoporotic changes in senescence leading to fractures. *Can Med Assoc J.* 1963;8:290–294.
6. Rose SH, Melton LJ, Morrey BF, Ilstrup DM, Riggs LB. Epidemiologic features of humeral fractures. *Clin Orthop.* 1982;168:24–30.
7. Codman EA. *The Shoulder, Rupture of the Supraspinatus Tendon and Other Lesions in or about the Subacromial Bursa*. Boston, MA: Thomas Todd; 1934:313–331.
8. Rockwood CA Jr, Williams GR, Young DC. Injuries to the acromioclavicular joint. In: Rockwood CA Jr, Green DP, Bucholz RW, eds. *Rockwood and Green's Fractures in Adults*. Vol 1. 3rd ed. Philadelphia, PA: JB Lippincott; 1991:1181–1252.
9. Jobe CM. Gross anatomy of the shoulder. In: Rockwood CA Jr, Matsen FA III, eds. *The Shoulder*. Vol 1. Philadelphia, PA: WB Saunders; 1998:34–97.
10. Bigliani LU, Morrison DS, April EW. The morphology of the acromion and rotator cuff impingement. *Orthop Trans.* 1987;11:234.
11. Warner JJP, Krushell RJ, Masquelet A, Gerber C. Anatomy and relationships of the suprascapular nerve: anatomical constraints to mobilization of the supraspinatus and infraspinatus muscles in the management of massive rotator-cuff tears. *J Bone Joint Surg Am.* 1992;74:36–45.
12. Ticker JB, Djurasovic M, Strauch RJ. Incidence of ganglion cysts and other variations in anatomy along the course of the suprascapular nerve. *J Shoulder Elbow Surg.* 1998;7:472–478.
13. Randelli M, Gambrioli PL. Glenohumeral osteometry by computed tomography in normal and unstable shoulders. *Clin Orthop.* 1986;208:151–156.
14. Morrey BF, Itoi E, Kai-Nan A. Biomechanics of the shoulder. In: Rockwood CA Jr, Matsen FA III, eds. *The Shoulder*. Vol 1. Philadelphia, PA: WB Saunders; 1998:233–263.
15. Ljunggren AE. Clavicular function. *Acta Orthop Scand.* 1979;50:261–268.
16. Craig EV. Fractures of the clavicle. In: Rockwood CA Jr, Matsen FA III, eds. *The Shoulder*. Vol 1. Philadelphia, PA: WB Saunders; 1998:428–482.
17. Hertz H. Die bedeutung des limbus glenoidalis fur die stabilitat des schultergelenks. *Wein Klin Wochenschr Suppl.* 1984;152:1–23.
18. Poppen NK, Walker PS. Normal and abnormal motion of the shoulder. *J Bone Joint Surg Am.* 1976;58:195–201.
19. Howell SM, Galinat BJ, Renzi AJ, Marone PJ. Normal and abnormal mechanics of the glenohumeral joint in the horizontal plane. *J Bone Joint Surg Am.* 1988;70:227–232.
20. McMahon P, Debski R, Thompson W, Warner J, Fu F, Woo S. Shoulder muscle forces and tendon excursions during glenohumeral abduction in the scapular plane. *J Shoulder Elbow Surg.* 1995;4:199–208.
21. Lippitt SB, Vanderhooft JE, Harris SL, Sidles JA, Harryman DT II, Matsen FA III. Glenohumeral stability from concavity-compression: a quantitative analysis. *J Shoulder Elbow Surg.* 1993;2:27–35.
22. Soslowsky LJ, Flatow EL, Bigliani LU, Mow VC. Articular geometry of the glenohumeral joint. *Clin Orthop.* 1992;285:181–190.
23. Gibb TD, Sidles JA, Harryman DT II, McQuade KJ, Matsen FA III. The effect of capsular venting on glenohumeral laxity. *Clin Orthop.* 1991;268:120–127.
24. Cole BJ, Warner JJP. Anatomy, biomechanics, and pathophysiology of glenohumeral instability. In: Iannotti JP, Williams GR Jr, eds. *Disorders of the Shoulder: Diagnosis and Management*. Philadelphia, PA; Lippincott Williams & Wilkins; 1999:207–232.
25. Cooper DE, Arnoczky SP, O'Brien SJ, Warren RF, DiCarlo E, Allen AA. Anatomy, histology, and vascularity of the glenoid labrum: an anatomical study. *J Bone Joint Surg Am.* 1992;74:46–52.
26. Howell SM, Galinat BJ. The glenoid-labral socket: a constrained articular surface. *Clin Orthop.* 1989;243:122–125.
27. Moseley H. Overgaard B. The anterior capsular mechanism in recurrent anterior dislocation of the shoulder: morphological and clinical studies with special reference to the glenoid labrum and the glenohumeral ligaments. *J Bone Joint Surg Br.* 1962;44:913–927.
28. Bankart ASB. The pathology and tratment of recurrent dislocation of the shoulder joint. *Br Med J.* 1923;2:1132–1133.
29. Pagnani M, Deng XH, Warren R, Torzilli P, O'Brien S. Role of the long head of the biceps brachii in glenohumeral stability: a biomechanical study in cadavera. *J Shoulder Elbow Surg.* 1996;4:255–262.
30. Pagnani M, Deng XD, Warren R, Torzilli P, Altchek D. Effect of lesions of the superior portion of the glenoid labrum on glenohumeral translation. *J Bone Joint Surg Am.* 1995;77:1003–1010.
31. O'Brien SJ, Neves MC, Arnoczky SP, et al. The anatomy and histology of the inferior glenohumeral ligament complex of the shoulder. *Am J Sports Med.* 1990;18:449–456.
32. Warner JJP, Deng XH, Warren RF, Torzilli PA. Static capsuloligamentous restraints to superior-inferior translation of the glenohumeral joint. *Am J Sports Med.* 1992;20:675–685.
33. Cole BJ, Warner JJP. Anatomy, biomechanics, and pathophysiology of glenohumeral instability. In: Iannotti JP, Williams GR Jr, eds. *Disorders of the Shoulder: Diagnosis and Management*. Philadelphia, PA: Lippincott Williams & Wilkins; 1999:207–232.
34. Basmajian JV, Bazant FJ. Factors preventing downward dislocation of the adducted shoulder joint. *J Bone Joint Surg Am.* 1959;41:1182–1186.
35. Boardman ND III, Debski RE, Warner JJP, et al. Tensile properties of the superior glenohumeral ligament and coracohumeral ligaments. *J Shoulder Elbow Surg*. 1996;5:249–254.
36. Turkel SJ, Panio MW, Marshall JL, Girgis FG. Stabilizing mechanisms preventing anterior dislocation of the glenohumeral joint. *J Bone Joint Surg Am.* 1981;63:1208–1217.
37. Inman VT, Saunders JB, Abbott LC. Observations on the function of the shoulder joint. *J Bone Joint Surg.* 1944;26:1–30.
38. Rodosky MW, Harner CD, Fu FH. The role of the long head of the biceps muscle and superior glenoid labrum in anterior stability of the shoulder. *Am J Sports Med.* 1994;22:121–130.
39. McCluskey GM III, Todd J. Acromioclavicular joint injuries. *J South Orthop Assoc.* 1995;4:206–213.
40. Bearn JG. Direct observations on the function of the capsule of the sternoclavicular joint in clavicular support. *J Anat.* 1967;101:159–170.
41. Rockwood CA Jr. Injuries to the sternoclavicular joint. In: Rockwood CA Jr, Green DP, Bucholz RW, eds. *Rockwood and Green's Fractures in Adults*. Vol 1. 3rd ed. Philadelphia, PA: JB Lippincott; 1991:1253–1308.
42. Sidles JA, Harryman DT, Matsen FA III. Glenohumeral and scapulothoracic contributions to shoulder motion. *Orthop Trans.* 1991;15:762.
43. Flatow EL. Shoulder anatomy and biomechanics. In: Post M, Flatow EL, Bigliani LU, Pollock RG. *The Shoulder: Operative Technique*. Baltimore, MD: Williams & Wilkins; 1998:1–42.