Functional Anatomy of the Shoulder Complex
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The shoulder complex, together with other joint and muscle mechanisms of the upper limb, primarily is concerned with the ability to place and control the position of the hand in the visual work space in front of the body. The shoulder mechanism provides the upper limb with a range of motion exceeding that of any other joint mechanism. The placement of the hand is determined by four components of the shoulder complex: the glenohumeral, acromioclavicular, and sternoclavicular joints and the scapulothoracic gliding mechanism. The clavicular joints permit the scapula to move against the chest wall during movements of the arm, allowing the glenoid fossa to follow the head of the humerus, and thus contribute significantly to total arm movement. The functional interrelationships between the glenohumeral, scapulothoracic, and clavicular joint mechanisms are critical in providing a full, functional ROM. Any pathological condition of any one of these mechanisms will disturb upper limb function. The ligamentous and periarticular structures of the shoulder complex combine in maintaining the joint relationships, withstanding the forces applied to the joint surfaces, and stabilizing the dependent limb.

Key Words: Acromioclavicular joint, Shoulder joint, Sternoclavicular joint.

The design of the shoulder complex is related directly to the overall function of the upper limb. The joint mechanisms of the limb permit the placement, functioning, and control of the hand directly in front of the body where the functions can be observed easily. Placement of the hand in the visual work space is controlled by the shoulder complex, which positions and directs the humerus; the elbow, which positions the hand in relation to the trunk; and the radioulnar joints, which determine the position of the palm.

The shoulder mechanism provides the upper limb with a range of motion exceeding that of any other joint mechanism. This ROM is greater than that required for the majority of daily activities. For example, self-feeding still is possible when the shoulder complex is immobilized with the humerus held by the side. Compensations for absent should motion is provided by the cervical spine, elbow, wrist, and finger joint mechanisms.

The shoulder complex consists of four joints that function in a precise, coordinated, synchronous manner. Position changes of the arm involve movements of the clavicle, scapula, and humerus. These movements are the result of the combined work of the sternoclavicular, acromioclavicular, and glenohumeral joints and the scapulothoracic gliding mechanism.

STERNOCLAVICULAR JOINT

The sternoclavicular joint is a synovial articulation. Although the structure of the joint is of the plane variety, its function most closely resembles a ball-and-socket articulation. The articular surfaces lack congruity. About half of the large, rounded medial (internal) end of the clavicle protrudes above the shallow sternal socket. The sternal surface of the clavicle has a small, upper nonarticular area that provides attachment for the important intra-articular disk. The remainder of the surface is saddle shaped, anteroposteriorly concave, and downwardly convex.

The medial end of the clavicle is bound to the sternum and to the first rib and its costal cartilage. Ligaments strengthen the fibrous capsule anteriorly, posteriorly, superiorly, and inferiorly. The principal joint structures stabilizing the joint, resisting the tendency for medial displacement of the clavicle, and limiting the clavicular component of arm movement are the articular disk and the costoclavicular ligament (Fig. 1).

The articular disk is fibrocartilaginous, strong and nearly circular, and completely divides the joint cavity. The disk itself is attached superiorly to the upper medial end of the clavicle and passes downward between the articular surfaces.

Fig. 1. The sternoclavicular joint with the major stabilizing components: the articular disk and costoclavicular ligament. (Adapted from Moore.)
transmitted through the arm will tend to drive the acromion to the first costal cartilage. This configuration permits the clavicle to override the sternum, resulting in medial dislocation.

The costoclavicular ligament is a strong, bilaminar fascicle attached to the inferior surface of the medial end of the clavicle and the first rib. The anterior component of the ligament passes upward and laterally (externally), the posterior part upward and medially. The ligament is a major stabilizing structure and strongly binds the medial end of the clavicle to the first rib. The ligament becomes taut when the arm is elevated or the shoulder protracted.

The joint capsule is supported by oblique anterior and posterior sternoclavicular ligaments. Both ligaments pass downward and medially from the sternal end of the clavicle to the anterior and posterior surfaces of the manubrium. The ligament becomes taut during pronation, and the anterior ligament is lax. During retraction, the opposite is true. An interclavicular ligament runs across the superior aspect of the sternoclavicular joint, joining the medial ends of the clavicles. This ligament, having deep fibers attached to the upper margin of the manubrium, provides stability to the superior aspect of the joint.

The areas of compression between the articular surfaces and the intra-articular disk vary with movements of the clavicle. When the clavicle moves in one direction during elevation, depression, retraction, or retraction, the ligaments on the side of the motion become lax. Those on the opposite side of the joint become taut, limiting the movement and causing the compression of the clavicle, disk, and sternum. During elevation and depression of the clavicle, most motion occurs between the clavicle and the disk. During pronation and retraction, the greatest movement occurs between the disk and the sternal articular surface. The combination of taut ligaments and pressure on the disk and articular surfaces is important in maintaining stability in the plane of motion. Forces acting on the clavicle from the upper limb rarely cause dislocation of the sternoclavicular joint. Excessive forces applied to the clavicle are most likely to cause a fracture of the bone medial to the attachment of the coracoclavicular ligament.

The movements of the sternoclavicular joint allow elevation and depression of the clavicle, as well as protraction and retraction. The axis for both movements lies close to the clavicular attachment of the costoclavicular ligament.

**ACROMIOCLAVICULAR JOINT**

The acromioclavicular joint is a synovial plane joint between the small, convex oval facet on the lateral end of the clavicle and a concave area on the anterior part of the medial border of the acromion process of the scapula. The articular surfaces are such that the joint line is oblique and slightly curved. The curvature of the joint permits the acromion, and thus the scapula, to glide forward or backward over the lateral end of the clavicle. This movement of the scapula keeps the glenoid fossa facing the humeral head. The oblique nature of the joint is such that forces transmitted through the arm will tend to drive the acromion process under the lateral end of the clavicle with the clavicle overriding the acromion (Fig. 2). The joint is important because it contributes to total arm movement in addition to transmitting forces between the clavicle and the acromion.

The acromioclavicular joint has a capsule and a superior acromioclavicular ligament that strengthen the upper aspect of the joint. The major ligamentous structure stabilizing the joint and binding the clavicle to the scapula is the coracoclavicular ligament. Although this ligament is placed medially and separate from the joint, it forms the most efficient means of preventing the clavicle from losing contact with the acromion (Fig. 3).

The coracoclavicular ligament consists of two parts: 1) the trapezoid and 2) the conoid (Fig. 3). These two components, functionally and anatomically distinct, are united at their corresponding borders. Anteriorly, the space between the two ligaments is filled with fat and, frequently, a bursa. A bursa also lies between the medial end of the coracoid process and the inferior surface of the clavicle. In up to 30% of subjects, these bony components may be opposed closely and may form a coracoclavicular joint. These ligaments suspend the scapula from the clavicle and transmit the force of the superior fibers of the trapezius to the scapula.

The trapezoid ligament, the anterolateral component of the coracoclavicular ligament, is broad, thin, and quadrilateral. It is attached from below to the superior surface of the coracoid process. The ligament passes laterally almost horizontally in the frontal plane to be attached to the trapezoid line on the inferior surface of the clavicle. A fall on the outstretched hand would tend to drive the acromion under the clavicle because of the tilt of the articular surfaces. This overriding is resisted by the trapezoid ligament.

The conoid ligament is located partly posterior and medial to the trapezoid ligament. It is thick and triangular, with its base attached from above to the conoid tubercle on the inferior surface of the clavicle. The apex, which is directed downward, is attached to the "knuckle" of the coracoid process (ie, medial and posterior edge of the root of the process). The conoid ligament is oriented vertically and twisted on itself. The ligament limits upward movement of the clavicle on the acromion. When the arm is elevated through abduction, the rotation of the scapula causes the coracoid process to move and increases the distance between the clavicle and the coracoid process. This movement also increases the tension on the conoid ligament, causing a backward axial rotation of the clavicle. If viewed from above, the clavicle has a shape resembling a crank. As scapular angulation occurs, the coracoid process is pulled downward and away from the clavicle. The taut coracoclavicular ligament then acts on the outer curvature of the crank-like clavicle and effects a rotation of the clavicle on its long axis. During full abduction of the arm, the clavicle rotates 50 degrees axially. This clavicular rotation permits the glenoid fossa to continue to elevate and increase the possible degree of arthral elevation. When the clavicle is prevented from rotating, the arm can be abducted actively to only 120 degrees.

Movement of the acromioclavicular joint is an important component of total arm movement. A principal role of the joint in the abduction of the arm is to permit continued lateral rotation of the scapula after about 100 degrees of abduction when sternoclavicular movement is restrained by the sternoclavicular ligaments. The acromioclavicular joint has three degrees of freedom. Movement can occur between the acromion and lateral end of the clavicle, about a vertical axis,
around a frontal axis, and about a sagittal axis. Functionally, the two major movements at the acromioclavicular joint, however, are a gliding movement as the shoulder joint flexes and extends and an elevation and depression movement to conform with changes in the relationship between the scapula and the humerus during abduction. \(^6,10,11\) The sternoclavicular and acromioclavicular joints play essential and distinct roles in the movements of the shoulder complex.

**GLENOHUMERAL JOINT**

The glenohumeral joint is a multiaxial ball-and-socket synovial joint. The articular surfaces, the head of the humerus and the glenoid fossa of the scapula, although reciprocally curved, are oval and are not sections of true spheres. Because the head of the humerus is larger than the glenoid fossa, only part of the humeral head can be in articulation with the glenoid fossa in any position of the joint. The surfaces are not congruent, and the joint is loose packed. Full congruence and the close-packed position are obtained when the humerus is abducted and rotated laterally. The design characteristics of the joint are typical of an “incongruous” joint. The surfaces are asymmetrical, the joint has a movable axis of rotation, and muscles related to the joint are essential in maintaining stability of the articulation. \(^4\) The humeral articular surface makes an angle of 130 to 150 degrees with the shaft and is retroverted about 20 to 30 degrees with respect to the axis of flexion of the elbow (Fig. 4). \(^14,15\)

The glenoid fossa is somewhat pear shaped. The surface area is one third to one fourth that of the humeral head. The vertical diameter is 75% and the transverse diameter is about 60% of that of the humeral head. In 75% of subjects, the glenoid fossa is retrotilted about 7.4 degrees in relationship to the plane of the scapula. This relationship is important in maintaining horizontal stability of the joint and counteracting any tendency toward anterior displacement of the humeral head. \(^15-17\)

**Glenoid Labrum**

The glenoid labrum is a rim of fibrocartilaginous tissue attached around the margin of the glenoid fossa. Some theories are that the labrum deepens the articular cavity, protects the edges of the bone, and assists in lubrication of the joint. \(^4,6,10\) Others are that the labrum does not increase the depth of the concave surface substantially. \(^15\) Moseley and Overgaard considered the glenoid labrum a fold of capsular tissue composed of dense fibrous connective tissue. \(^18\) The inner surface of the labrum is covered with synovium; the outer surface attaches to the capsule and is continuous with the periosteum of the scapular neck. The shape of the labrum adapts to accommodate rotation of the humeral head, adding flexibility to the edges of the glenoid fossa. The tendons of the long head of the biceps brachii and triceps brachii muscles contribute to the structure and reinforcement of the labrum. The labrum seems to represent a fold of the capsule, however, and its major function may be to serve as an attachment for the glenohumeral ligaments. \(^4,18\)

**Capsule**

The capsule surrounds the joint and is attached medially to the margin of the glenoid fossa beyond the labrum. Laterally, it is attached to the circumference of the anatomical...
neck, and the attachment descends about a half-inch onto the shaft of the humerus. The capsule is loose fitting to the extent that the joint surfaces can be separated 2 to 3 mm by a distractive force.13

The capsule is relatively thin and, by itself, would contribute little to the stability of the joint. The integrity of the capsule and the maintenance of the normal glenohumeral relationship depend on the reinforcement of the capsule by ligaments and the attachment of the muscle tendons of the rotator cuff mechanism.4,10,11

The superior part of the capsule, together with the coracohumeral ligament, is important in strengthening the superior aspect of the joint and resisting the effect of gravity on the dependent limb.4,19 Anteriorly, the capsule is strengthened by the glenohumeral ligaments and the attachment of the subscapularis tendon. The latter is a major dynamic stabilizer of the anterior aspect of the shoulder. Posteriorly, the capsule is strengthened by the attachment of the teres minor and infraspinatus tendons. Inferiorly, the capsule is thin and weak and contributes little to the stability of the joint. The inferior part of the capsule is subjected to considerable strain because it is stretched tightly across the head of the humerus when the arm is elevated.

The inferior part of the capsule, the weakest area, is lax and lies in folds when the arm is adducted. In capsular fibrosis of the shoulder, these redundant folds of the capsule adhere to one another.10,13 Kaltsas compared the collagen structure of the shoulder joint with that of the elbow and hip.20 When the joint capsules were subjected to a mechanical force, the shoulder joint capsule showed a greater capacity to stretch than to rupture. When the capsule was tested to failure, the structure ruptured anteroinferiorly.20,21 The frequency of anterior dislocation seen clinically demonstrates the weakness of the inferior part of the capsule.20

The orientation of the capsule influences the movement of the glenohumeral joint. With the arm by the side, the capsular fibers are oriented with a forward and medial twist (Fig. 5). This twist increases in abduction and decreases in flexion. The capsular tension in abduction compresses the humeral head into the glenoid fossa. As abduction progresses, the capsular tension exerts an external rotation moment. This external rotation “untwists” the capsule and allows further abduction.19 The external rotation of the humerus during abduction thus may be assisted by the configuration of the joint capsule.19,22

The capsule is lined by a synovial membrane attached to the glenoid rim and anatomical neck inside the capsular attachments.4 The tendon of the long head of the biceps brachii muscle passes from the supraglenoid tubercle over the head of the humerus and lies within the capsule, emerging from the joint at the intertubercular groove. The tendon is covered by a synovial sheath to facilitate movement of the tendon within the joint. The structure is susceptible to injury at the point at which the tendon arches over the humeral head and the surface on which it glides changes from bony cortex to articular cartilage.6

Coracohumeral Ligament

The coracohumeral ligament is one of the most important ligamentous structures in the shoulder complex.19 The ligament is attached to the base and lateral border of the coracoid process and passes obliquely downward and laterally to the front of the greater tuberosity, blending with the supraspinatus muscle and the capsule. The ligament blends with the rotator cuff and fills in the space between the subscapularis and supraspinatus muscles. The anterior border of the ligament is distinct medially and merges with the capsule laterally. The posterior border is indistinct and blends with the capsule (Fig. 6).4,10

The coracohumeral ligament is important in maintaining the glenohumeral relationship. The downward pull of gravity on the arm is counteracted largely by the superior capsule and the coracohumeral ligament. These structures function together with the supraspinatus and posterior deltoid muscles. The lateral slope of the glenoid fossa also provides support to the humeral head. Because the coracohumeral ligament is located anterior to the vertical axis about which the humerus rotates axially, the ligament checks lateral rotation and extension. Shortening of the ligament would maintain the glenohumeral relationship in medial rotation and would restrict lateral rotation severely.13

Glenohumeral Ligaments

The three glenohumeral ligaments lie on the anterior aspect of the joint (Fig. 7). They frequently are described as being thickened parts of the capsule.4 The superior glenohumeral ligament passes laterally from the upper part of the glenoid labrum and the base of the coracoid process to the upper part of the humerus between the upper part of the lesser tuberosity and the anatomical neck. The ligament lies anterior to and partly under the coracohumeral ligament. The superior glenohumeral ligament, together with the coracohumeral ligament and the supraspinatus muscle, assists in preventing downward displacement of the humeral head.23
A diagram illustrating the relationship between the glenohumeral ligaments and the articular margin.

The middle glenohumeral ligament has a wide attachment extending from the superior glenohumeral ligament along the anterior margin of the glenoid fossa as far as the junction of the middle and inferior thirds of the glenoid rim. From this attachment, the ligament passes laterally, gradually enlarges, and attaches to the anterior aspect of the anatomical neck of the humerus. The ligament lies under the tendon of the subscapularis muscle and partly adheres to it. The middle glenohumeral ligament limits lateral rotation up to 90 degrees of abduction and is an important anterior stabilizer of the shoulder joint, particularly effective in the middle ranges of abduction.

The inferior glenohumeral ligament is the thickest of the glenohumeral structures. The ligament attaches to the anterior, inferior, and posterior margins of the glenoid labrum and passes laterally to the inferior aspects of the anatomical and surgical necks of the humerus. The anterosuperior edge of this ligament is thickened and is termed the superior band. The inferior part is thinner and broader and is termed the axillary pouch. The superior band strengthens the capsule anteriorly and supports the joint most effectively in the middle ranges of abduction.

The rotator cuff is the musculotendinous complex formed by the attachment to the capsule of the supraspinatus muscle superiorly, the subscapularis muscle anteriorly, and the teres minor and infraspinatus muscles posteriorly. All of their tendons blend intricately with the fibrous capsule. They provide active support for the joint and can be considered true dynamic ligaments. The capsule is less well protected inferiorty because the tendon of the long head of the triceps brachii muscle is separated from the capsule by the axillary nerve and the posterior circumflex humeral artery.

The rotator cuff, acting as a dynamic, compound musculotendinous unit, plays an essential role in movements of the glenohumeral joint. Lesions of the rotator cuff mechanism can occur as a response to repetitious activity over time or to overload activity that causes a spontaneous lesion. Stress applied to a previously degenerated rotator cuff may cause the cuff to rupture. Often, this stress also tears the articular capsule, resulting in a communication between the joint cavity and the subacromial bursa. Rotator cuff tears result in considerably reduced force of elevation of the shoulder joint. In attempting to elevate the arm, the patient shrugs the shoulder. If the arm is abducted passively to about 90 degrees, the patient should be able to maintain the arm in the abducted position.

**Coracoacromial Ligament**

This strong triangular ligament has a base attached to the lateral border of the coracoid process (Fig. 8). The ligament passes upward, laterally and slightly posteriorly, to the top of the acromion process. Superiorly, the ligament is covered by the deltoid muscle. Posteriorly, the ligament is continuous with the fascia that covers the supraspinatus muscle. Anteriorly, the coracoacromial ligament has a sharp, well-defined, free border. Together with the acromion and the coracoid processes, the ligament forms an important protective arch over the glenohumeral joint. The arch forms a secondary restraining socket for the humeral head, protecting the joint from trauma from above and preventing dislocation of the humeral head superiorly. The supraspinatus muscle passes under the coracoacromial arch, lies between the deltoid muscle and the capsule of the glenohumeral joint, and blends with the capsule. The supraspinatus tendon is separated from the arch by the subacromial bursa (Fig. 9).

During elevation of the arm in both abduction and flexion, the greater tuberosity of the humerus may apply pressure against the anterior edge and the inferior surface of the anterior third of the acromion and the coracoacromial ligament. In some instances, the impingement also may occur against the acromioclavicular joint. Most upper extremity functions are performed with the hand positioned in front of the shoulder, not lateral to it. The shoulder is used most frequently in the forward, not lateral, position. When the arm is raised forward in flexion, the supraspinatus tendon passes under the anterior edge of the acromion and the acromioclavicular joint. For this movement, the critical area for wear is centered on the supraspinatus tendon and also may involve the long head of the biceps brachii muscle.

**Bursae**

Several bursae are found in the shoulder region. Two bursae particularly are important to the clinician: the subacromial and the subscapular bursa. Other bursae located in relation to the glenohumeral joint structures are between the infraspinatus muscle and the capsule, on the superior surface of the acromion, between the coracoid process and the capsule, under the coracobrachialis muscle, between the teres major and the long head of the triceps brachii muscles, and in front of and behind the tendon of the latissimus dorsi muscle. Because they are located where motion is required between adjacent structures, bursae have a major function in the shoulder mechanism. The subacromial bursa is located between the deltoid muscle and the capsule, extending under the acromion and the coracoacromial ligament and between them and the supraspinatus muscle. The bursa adheres to the coracoacromial ligament and to the acromion from above and to the rotator cuff from below. Usually, the bursa does not communicate with the joint; however, a communication may develop if the rotator cuff is ruptured. The subacromial bursa is important for allowing gliding between the acromion and the deltoid muscle and the rotator cuff. It also reduces
friction on the supraspinatus tendon as it passes under the coracoacromial arch.10

The subscapular bursa lies between the subscapularis tendon and the neck of the scapula. It protects this tendon where it passes under the base of the coracoid process and over the neck of the scapula. The bursa communicates with the joint cavity between the superior and middle glenohumeral ligaments.10,23

**SCAPULOTHORACIC MECHANISM**

Except for attachments through the acromioclavicular and sternoclavicular joints, the scapula is without bony or ligamentous attachments to the thorax.4 The scapulothoracic gliding mechanism is not a true joint but is the riding of the concave anterior surface of the scapula on the convex posterolateral surface of the thoracic cage.1,4 The thorax and scapula are separated by the supraspinalis and serratus anterior muscles, which glide over each other during movements of the scapula.4 The scapula is held in close approximation to the chest wall by muscular attachments. In movements of the shoulder complex, the scapula can be protracted, retracted, elevated, depressed, and rotated about a variable axis perpendicular to its flat surface.11

**VASCULAR SUPPLY**

The rotator cuff is a frequent site of pathological conditions, usually degenerative and often in response to fatigue stress.13 Because degeneration may occur even with normal activity levels, the nutritional status of the glenohumeral structures is of great importance. The blood supply to the rotator cuff comes from the posterior humeral circumflex and the suprascapular arteries.4 These arteries supply principally the infraspinatus and teres minor muscle areas of the cuff. The anterior aspect of the capsular ligamentous cuff is supplied by the anterior humeral circumflex artery and occasionally by the thoracoacromial, suprahumeral, and subscapular arteries. Superiorly, the supraspinatus muscle is supplied by the thoracoacromial artery. The supraspinatus and infraspinatus regions of the cuff may be hypovascular with respect to the other components of the rotator cuff.27,28 Rothman and Parke demonstrated that, regardless of the age of the subjects, the supraspinatus region was hypovascular in 63% of 72 specimens and the infraspinatus region in 37%.27 The hypovascularity of the supraspinatus tendon is related also to pressure and tension exerted on the tendon as it passes under the coracoacromial ligament.28

**ARTICULAR NEUROLOGY**

Both the superficial and deep structures of the articular region are richly innervated.2 Nerve fibers are derived chiefly from C5, C6, and C7; C4 also may add a minor contribution. The nerves supplying the ligaments, capsule, and synovial membrane are the axillary, suprascapular, subscapular, and musculocutaneous nerves. In addition, branches from the
posterior cord of the brachial plexus may supply the joint structures.

The innervation pattern is variable. In some instances, the shoulder may receive a greater supply from the axillary nerve than from the musculocutaneous nerve. In other instances, the reverse is true. Because the nerves are supplied from many sources, denervation of the joint is difficult. The nerve supply follows the small blood vessels into periarticular structures.\(^4\)\(^6\)\(^7\)

The skin on the anterior region of the shoulder is supplied by the supraclavicular nerves from C3 and C4 and by the terminal branches of the sensory component of the axillary nerve. The deep structures of the anterior aspect of the joint are innervated by branches from the axillary nerve, and, to a lesser degree, by contributions from the suprascapular nerves. In some instances, the musculocutaneous nerve may supply the superior aspect of the joint. In addition, the subscapular nerve or the posterior cord of the brachial plexus may send some fibers to the anterior aspect of the joint after piercing the subscapularis muscle.\(^4\)\(^6\)\(^10\)

The supraclavicular nerves also supply the skin on the superior and upper posterior aspects of the shoulder. The lower, posterior, and lateral aspects of the shoulder are supplied by the posterior branch of the axillary nerve.

Superiorly, the periarticular structures obtain part of their innervation from two branches of the suprascapular nerve. One branch passes anteriorly as far as the coracoid process and the coracoacromial ligament. The other branch supplies the posterior aspect of the joint. In some instances, the axillary and musculocutaneous nerves and the lateral pectoral nerve contribute to the innervation of the superior aspect of the joint. Posteriorly, the principal nerve supply comes from the suprascapular nerve, which supplies the upper part of the joint, and the axillary nerve, which supplies the lower region.\(^2\)\(^4\)\(^6\)\(^10\)

The acromioclavicular joint is innervated by the lateral supraclavicular nerve from the cervical plexus (C4) and by the lateral pectoral and suprascapular nerves from the brachial plexus (C5 and C6). The sternoclavicular joint is innervated by branches from the medial supraclavicular nerve from the cervical plexus (C3 and C4) and the subclavian nerve from the brachial plexus (C5 and C6).\(^4\)\(^10\)

**MOVEMENTS OF THE SHOULDER COMPLEX**

The design of the shoulder complex provides the upper limb with an extensive range of movement. The design characteristics enable the hand to function effectively in front of the body in the visual work space.\(^29\) All four joints of the shoulder complex—the glenohumeral, the acromioclavicular, the sternoclavicular, and the scapulothoracic—contribute to total arm movement.\(^4\)

**Movement of the Humerus and Scapula**

The displacement of the articular surfaces at the glenohumeral joint are considered as movements of a convex ovoid surface (head of the humerus) relative to a concave ovoid surface (glenoid fossa). The articular humeral head rolls, slides, and spins. The rolling occurs in a direction opposite that of the sliding. The multiaxial design of the glenohumeral joint permits an infinite variety of combinations of these movements.\(^4\) Classically, the joint is considered to permit the movements of flexion-extension, abduction-adduction, circumduction, and medial-lateral rotation.\(^4\) In the movements of the glenohumeral joint, displacement of a reference point of the convex ovoid surface relative to the concave ovoid surface is amplified by the distal end of the extremity. This means that all possible displacements of the distal end of the upper extremity occur in a curved segment of space. This curved segment is termed the *ovoid of motion or field of motion.* The shortest distance from one point to another on an ovoid surface is termed a *chord,* and the shortest displacement is a *cardinal displacement.*\(^4\) At the glenohumeral joint, when two cardinal displacements occur one after the other at a right angle, spin or axial rotation is involved. This is an important feature of glenohumeral joint movement.\(^4\)

The mechanical midposition of the glenohumeral articulation, when the center of the humeral head is in contact with the center of the glenoid fossa, occurs in the frontal plane when the arm is elevated 45 degrees midway between flexion and abduction with slight medial rotation.\(^29\)\(^30\) The position of the best fit when the joint is in the close-packed position, however, occurs in full abduction with lateral rotation.\(^4\) The lateral and forward direction of the glenoid fossa is determined by the position of the scapula. The plane of the scapula is 30 degrees to 45 degrees anterior to the frontal plane. Movements of the humerus in relation to the glenoid fossa can be described in relation to the frontal and coronal planes or in relation to the plane of the scapula.\(^22\)\(^32\)

The glenohumeral structures are in a position of optimum alignment when movements are performed in relation to the scapula.\(^22\) Some authors have suggested that “true abduction” of the arm occurs not in the frontal plane but rather in the plane of the scapula.\(^13\)\(^22\) In the plane of the scapula, the capsule is not twisted, and the deltoid and supraspinatus muscles are aligned optimally for elevating the arm.

The mechanism of elevation of the arm is complex and includes glenohumeral and scapulothoracic movement. These components are important to consider when studying this mechanism. Poppen and Walker stated that, in the relaxed position with the arm by the side, the long axis of the humerus makes an angle from the vertical plane of 2.5 degrees with a range from \(-3.0\) to 9.0 degrees.\(^32\) The angle between the face of the glenoid fossa and the vertical plane, the scapulothoracic angle, ranges from \(-11.0\) to 10.0 degrees.\(^32\)\(^33\)

In the first 30 degrees of arm abduction, the scapula moves only slightly when compared with the humerus. Poppen and Walker reported a ratio of 4.3:1 for glenohumeral to scapulothoracic movement.\(^32\) Within this same range, the humeral head moves upward on the face of the glenoid fossa by about 3 mm. As abduction progresses, the glenoid fossa moves medially, then tilts upward, and finally moves upward as the arm approaches full elevation. The scapula rotates from 0 to 30 degrees about its lower midportion and then, after 60 degrees, the center of rotation shifts toward the glenoid fossa.\(^32\)

Poppen and Walker stated that, when abduction of the arm is viewed from the side, lateral rotation of the scapula is accompanied by a counterclockwise rotation of the scapula.\(^32\) This movement occurs about a frontal axis. In this movement, the coracoid process moves upward and the acromion backward. The mean amount of this twisting is 40 degrees at full elevation. In this movement, the superior angle of the scapula moves away from the body wall, and the inferior angle moves into the body. This motion is important functionally when considered together with the lateral rotation of the humerus during abduction of the arm. The counterclockwise rotation of the scapula, during which the acromion process moves backward, occurs as the humerus itself rotates laterally. The humerus and scapula move synchronously, so the relative amount of rotation between the two bones may be small. Lateral rotation of the humerus in relation to the scapula is
essential, however, because it allows the greater tubercle to clear the acromion, thus preventing impingement. The lateral rotation is a function of the activity of the infraspinatus and teres minor muscles and of the possible force of the twisting of the glenohumeral capsule. If the arm is rotated medially, only 60 degrees of glenohumeral movement is possible either passively or actively.

After 30 degrees, the movement of arm abduction is characterized by rotation of the clavicle and the scapula about an imaginary axis extending from the sternoclavicular joint to the root of the spine of the scapula (Fig. 10). Although the clavicle and the scapula move together, the root of the spine is stationary relatively. This design gives the shoulder girdle considerable stability. This movement of the scapula and the clavicle continues until the costoclavicular ligament becomes taut at about 100 degrees of elevation, rendering impossible any further movement of the sternoclavicular joint about the sternoclavicular root of the spine axis. Because the scapula has to continue to rotate laterally, the only option for the scapula-clavicle link is for the acromioclavicular joint to become the center of rotation. In this movement, the root of the spine of the scapula, which relatively has been stationary, moves laterally (Fig. 11).

As the arm approaches full elevation, the acromioclavicular joint ceases to move when the trapezoid ligament becomes taut. After this action, the scapula and the clavicle again move as a single unit. During this range of abduction, the clavicle rotates about its long axis. This crankshaft rotation is imposed on the clavicle by the tension of the coracoclavicular ligament.

After the initial 30 degrees of abduction, glenohumeral and scapulothoracic joint movements occur simultaneously and contribute to elevation of the arm. The ratio of glenohumeral to scapulothoracic motion is reported as 1.25:1, 1.35:1, 2:1, and 2.34:1. The ratio of glenohumeral to scapulothoracic motion may vary with the plane and arc of elevation, the load on the arm, and the anatomical variations among individuals.

In summary, the initial 30 degrees of arm abduction are essentially the result of glenohumeral motion. From 30 degrees to full arm abduction, movement occurs at the scapulothoracic and glenohumeral joints. The movement of the scapula is essentially the product of the movement of the sternoclavicular and acromioclavicular joints. Approximately 40 degrees of the total range of abduction are the product of sternoclavicular motion, and 20 degrees the contribution of the acromioclavicular joint. A similar relationship occurs if the arm is elevated through flexion. Medial rotation of the humerus accompanies shoulder flexion.

Viewed from above, at rest, the scapula makes an angle of 30 degrees with the frontal plane and an angle of 60 degrees with the clavicle. This position directs the glenoid fossa forward and laterally. The position of the scapula against the chest wall is critical in providing a stable base for movements of the upper limb. The scapulothoracic relationship is not that of a true joint, but is the contact of the anterior surface of the scapula with the external surface of the thorax. The anterior surface of the scapula is concave and corresponds to the convex thoracic curvature. The scapula is retained in place principally by the muscle masses that pass from the axial skeleton to the scapula: the trapezius, serratus anterior, rhomboid major and minor, and levator scapulae muscles. The movements of the scapula are related essentially to the functional demands of the upper limb and to the requirements for positioning and using the hand. Movements of the scapula, when considered primarily as movements of the scapulothoracic relationship, are elevation, depression, protraction, retraction, and medial and lateral rotation.
Dynamic Stability

A number of related factors influence the stability of the glenohumeral joint. A shallow glenoid fossa, one third of the articular surface of the humerus, creates a potential for instability.\textsuperscript{16} Instability in the glenohumeral joint is mostly anterior, to a lesser extent inferior, and least of all posterior. The short rotator muscles exerting a force in a downward and medial direction in abduction are critical in controlling the position of the humeral head.\textsuperscript{10} The posterior tilt of the glenoid fossa, together with the posteriorly tilting humeral head, provides a relationship that also counteracts the tendency toward horizontal (anterior) instability.\textsuperscript{10} In addition to these factors, the capsule and the glenohumeral ligaments are important in maintaining stability in movements of the glenohumeral joint. Common causes of instability include abnormalities of the articular surface's size, shape, and orientation; disruptions of the capsule, glenohumeral ligaments, and labrum; and the inadequacy of the short rotator muscles, particularly the subscapularis.\textsuperscript{11,16,21}

The sternoclavicular joint is the only point of attachment of the upper limb to the axial skeleton. This joint, together with muscle masses of the upper trapezius, levator scapulae, and sternomastoid, assists in supporting the shoulder girdle, from which the upper limb is suspended. The scapula and, indirectly, the upper limb hang from the lateral end of the clavicle through the coracoclavicular and acromioclavicular capsule and ligaments.\textsuperscript{15} The support of the limb at the glenohumeral joint is partly the function of the slope of the glenoid fossa. The lateral tilt or slope of the glenoid fossa pushes the humeral head laterally. The tendency for the humeral head to move laterally is prevented by the superior glenohumeral and coracohumeral ligaments and the supraspinatus muscle. A change in the direction of the glenoid fossa, as seen in stroke patients when the scapula is depressed and rotated medially, can result in downward subluxation of the joint.\textsuperscript{19}

No single structure is responsible primarily for stability in all positions of the upper limb. As the arm is elevated, the support function of the muscles, capsule, and ligaments shifts from superior to inferior structures. In the dependent position, stability is maintained by the supraspinatus muscle, the superior glenohumeral ligament, and the coracohumeral ligament. In the middle range of abduction, the support function passes to the subscapularus muscle, the middle glenohumeral ligament, and the superior band of the inferior glenohumeral ligament. In the upper ranges of elevation, the axillary pouch of the inferior glenohumeral ligament stabilizes and supports the glenohumeral relationship.\textsuperscript{22}

Effects of Aging

The weakest point of the articular structures in the shoulder in young persons is the glenoid labrum attachment. In elderly persons, the weakest parts are the capsule and the subscapularis tendon.\textsuperscript{21,24} The changes associated with aging include the transformation of the rotator cuff to fibrocartilage, particularly at the area where the cuff is inserted into the humerus. A decrease in collagen is associated with an increase in the cross-linkage of collagen fibers, which creates a loss of resilience in the cuff. The tendinous fibers of the rotator cuff, at or near their insertion into the tuberosities, undergo degenerative changes with advancing age. Deterioration is pronounced after the fifth decade of life and occurs in all shoulders of persons more than 60 years of age. The point of attachment to the tuberosities, where degenerative changes are most severe, is known as the critical area. Calcified deposits also are seen at this site.\textsuperscript{34} Superficial tears occur chiefly near the margin of the cuff. Full-thickness tears can occur in any part of the cuff.\textsuperscript{6} Nearly all cuff tears occur in the anterior portion of the cuff and occur close to the point of bony attachment.\textsuperscript{6}

In the aging shoulder, subluxation of the humeral head usually is upward (80% of abnormal shoulders).\textsuperscript{40} Upward subluxation is secondary to injury of the rotator cuff. Rheumatoid arthritis, stroke, and previous injury are the most common predisposing factors in subluxation. Subluxation, however, may be no more than a reflection of aging, lax musculature, or mild abnormality of joint structures.\textsuperscript{24,41}

FORCES ACTING ON THE SHOULDER

Although the glenohumeral joint frequently is referred to as nonweight bearing, significant loads are applied to the joint during daily function.\textsuperscript{11} Calculations of compression forces at the shoulder have varied among investigators. Reports range from about 50% to over 90% of body weight.\textsuperscript{7,11,42} In most joints, passive forces from ligaments and joint surfaces contribute more stability than at the shoulder where equilibrium of the humeral head is achieved largely through interaction of active forces.\textsuperscript{34,35}

Poppen and Walker considered the various muscles active in each phase of abduction and then calculated the compressive, shear, and resultant forces at the glenohumeral joint.\textsuperscript{43} The resultant forces increased linearly with abduction to reach a maximum of 0.89 times body weight at 90 degrees of abduction. After 90 degrees of abduction, the resultant force decreased to 0.4 times body weight at 150 degrees of abduction. The shearing component up the face of the glenoid fossa was a maximum of 0.42 times body weight at 60 degrees of abduction. At 0 degrees, with the arm by the side, the humeral head was subluxating downward; from 30 to 60 degrees, the resultant force was close to the superior edge of the glenoid fossa, indicating a tendency to subluxate upward. After 60 degrees, the head of the humerus was compressed directly into the center of the glenoid fossa. Based on the theory that inherent joint stability in the scapular plane increases the closer the force vector is to the center of the glenoid fossa, Poppen and Walker concluded that lateral rotation provides greater stability than medial rotation.\textsuperscript{45}

Because the glenohumeral joint potentially is unstable, a muscle acting on the humerus must function together with other muscles to avoid producing a subluxating force on the joint. The multiple joint system of the shoulder complex requires that some muscles may span, and so influence, more than one joint. In addition, muscle function will be influenced by the relative positions of the bones. Subsequently, the influence a muscle will have on the joints will vary throughout the range of shoulder movement.\textsuperscript{11}

The deltoid muscle and the rotator cuff mechanism are the essential motor components necessary for the abduction of the humerus. The force of elevation, together with the active downward pull of the short rotator muscles, establishes the muscle force couple necessary for elevation of the limb. When the arm is by the side, the direction of the deltoid muscle force is upward and outward with respect to the humerus, whereas the force of the infraspinatus, teres minor, and subscapularis muscles is downward and inward. The force of the deltoid muscle, acting below the center of rotation, is opposite that of the force of the three short rotator muscles, applied
above the center of rotation. These forces act in opposite
directions on either side of the center of rotation and produce
a powerful force couple.\textsuperscript{8} The magnitude of the force required
to bring the limb to 90 degrees of elevation is 8.2 times the
weight of the limb. After 90 degrees, the force requirement
decreases progressively, reaching zero at 180 degrees. The
force requirements of the short rotator component of the
muscle force couple reach the maximum at 60 degrees of
abduction, at which time the force requirements are 9.6 times
the weight of the limb. After 90 degrees, the magnitude of the
force decreases progressively, reaching zero at 135 degrees.\textsuperscript{7}

As abduction progresses, the pull of the deltoid muscle
forces the humerus more directly into the glenoid fossa. In
higher ranges of abduction, the pull of the deltoid muscle
forces the head of the humerus downward. In complete loss
of deltoid muscle function, the rotator cuff, including the
supraspinatus muscle, can produce abduction of the arm with
50\% of normal force.\textsuperscript{8} Absence of the supraspinatus muscle
alone, provided the shoulder is pain free, produces a marked
loss of force in the higher ranges of abduction. The force in
abduction is lost rapidly, and by 90 degrees of combined
humeral and scapular motion, the weight of the arm only
can be lifted against gravity.\textsuperscript{8}

The long head of the biceps brachii muscle also assists in
stabilizing the glenohumeral articulation during abduction.
The tendon of the biceps brachii muscle has a pulley-like
relationship with the upper end of the humerus, and it exerts
a force downward against the humeral head.\textsuperscript{7} If the arm is
rotated laterally so that the bicipital groove faces laterally, the
long head of the biceps brachii muscle functions as a pulley
to assist in abduction of the arm.\textsuperscript{13}

FORCE EQUILIBRIUM OF THE ROTATOR CUFF
MUSCLES

The intrinsic rotator cuff muscles—the subscapularis, the
infraspinatus, the teres minor, and the supraspinatus—are active
during abduction and lateral rotation.\textsuperscript{46} When the
influence of these muscles on the glenohumeral joint is con-
sidered, the teres minor and the infraspinatus muscles can be
considered as a single unit. An equilibrium analysis of
glenohumeral forces described by Morrey and Chao was based
on three notions: 1) Each muscle acts with a force in propor-
tion to its cross-sectional area, 2) each muscle is equally active,
and 3) the active muscle contracts along a straight line con-
necting the center of its insertion to the center of its origin.\textsuperscript{47}

The three-dimensional equilibrium configuration of the
arm abducted to 90 degrees and in lateral rotation shows a
compressive force of 70 kg, an anterior shear force of 12 kg,
and an inferior shear force of 14 kg. The resultant of the three
forces is directed 12 degrees anteriorly. The subscapularis
muscle is the primary rotator cuff muscle responsible for
preventing anterior displacement of the humeral head. If the
shoulder is extended backward 30 degrees in 90 degrees of
abduction and is loaded so that all the rotator cuff muscles
are contracting maximally, the anterior shear force is in-
creased to almost 42 kg. This force must be counteracted
by the capsule and ligaments because the articular surfaces pro-
vide little stabilizing effect. The tensile strength of the capsule
and ligament complex averages 50 kg. When the subscapularis
muscle is added to the capsule and ligaments, the combined
tensile strength of the anterior structures is about 120 kg.\textsuperscript{47}

Several factors are related to the forces acting on the gle-
nohumeral joint. The relationship of these forces alters as the

limb assumes different positions. The principal factors influ-
encing the nature and degree of the glenohumeral forces are the
1) articular surfaces, 2) deltoid muscle, 3) supraspinatus
muscle, 4) weight of the arm, 5) rotator cuff muscles, 6) capsule
and ligaments, and 7) position of the arm.\textsuperscript{8,15-17,32}

SCAPULOTHORACIC FORCES

An examination of the muscles connecting the scapula with
the axial skeleton shows that all except for the upper fibers of
the trapezius and pectoralis minor muscles are inserted near
or on the medial border of the scapula.\textsuperscript{3,4,7} These include
the upper and lower digitations of the serratus anterior muscle,
the levator scapulae muscle, the rhomboid major and minor
muscles, and the lower fibers of the trapezius muscle. Consid-
ering the forces and moments developed about the base of
the scapular spine during the early stages of abduction of the
arm, a consistent mechanical pattern is seen.\textsuperscript{14} The major
influence of the upper fibers of the serratus anterior muscle
and the abduction force applied to the scapula by the rotator
cuff muscles are balanced by the rhomboid, levator scapulae,
and lower fibers of the trapezius muscles.\textsuperscript{7} This influence
stabilizes the root of the spine of the scapula, which is the
center of rotation for movement up to 100 degrees of abduc-
tion. As rotation of the scapula progresses past this point, the
principal source of activity is the lower part of the serratus
anterior muscle. The upper part of the trapezius muscle
primarily opposes the pull of the deltoid muscle, and it has
limited influence on scapular rotation (Fig. 12).\textsuperscript{2,14,31,38,44} The
serratus anterior muscle is an essential factor in stabilizing
the scapula in the early phase of abduction, in addition to
upwardly rotating the scapula. The lower fibers of the serratus
anterior muscle are oriented to exert moments effectively
about both the root of the scapular spine and the acromiocla-
vicular joint during the initial and later phases of abduc-
tion.\textsuperscript{7,31,38,44} The serratus anterior muscle has the longest mo-
ment arm of the relevant muscles. Reduced activity of serratus
anterior muscle has been demonstrated in both neurological
and soft tissue lesions affecting the shoulder complex.\textsuperscript{48-50} The
majority of the literature on the influence of the scapulohu-
meral, axioascapular, and axiohumeral muscles of the shoulder
complex has dealt with the “action” of the muscles. Little
CONCLUSION

The articular surfaces of the glenohumeral joint contribute little to stability, and the dynamic relationships of the joint are largely the function of the soft tissue elements. The glenohumeral capsule, coracohumeral and glenohumeral ligaments, and the rotator cuff mechanism have significant and precise roles in maintaining joint stability and in influencing the range and direction of movement.

The clavicular joints influence the ROM and the contribution of the scapula to total arm movement. The scapulothoracic component of upper limb movement is the product of sternoclavicular and acromioclavicular joint mobility. The major structures influencing the clavicular joint mechanisms are the coracoclavicular and costoclavicular ligaments and the articular disk of the sternoclavicular joint. The clavicle also plays a vital role in the transfer of forces to the axial skeleton and the suspension of the dependent upper limb.

During elevation of the upper limb, the interactive forces of the flexor and abductor muscles of the humerus and the infraspinatus muscles create a vital mechanical force couple that maintains and controls the glenohumeral relationship. Because the articular surfaces of the joints of the shoulder complex contribute little to the stability of the joint mechanism, the ligaments and periaricular structures are of prime importance in maintaining joint relationships and permitting normal function.

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