Biomechanics of the Shoulder

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Introduction

The glenohumeral (GH) joint has the greatest range of motion of any joint in the human body. As such, it has inherent instability, as its great range of motion is afforded by the lack of bony restraint [1–5]. Its functional structure permits significant rotation while maintaining the humeral center of rotation to within 1–2 mm with respect to the glenoid. Limitation of translation during active shoulder motion occurs through complex interactions between passive structures (ligaments, capsule, labrum, articular surfaces) and active structures (rotator cuff muscles, biceps brachii muscle, deltoid), which produce a concavity-compression effect of the humeral head on the glenoid [6–10]. The humeral head has an articulating surface area that is approximately three times that of the glenoid despite a similar radius of curvature, which means the humerus is only loosely constrained by the glenoid bony anatomy. Simple geometry shows that dislocation of the humeral head from the glenoid fossa should require a translation approximately half of the sum of the glenoid and humeral head axes in the direction of dislocation (Fig. 2.1). In the normal shoulder,

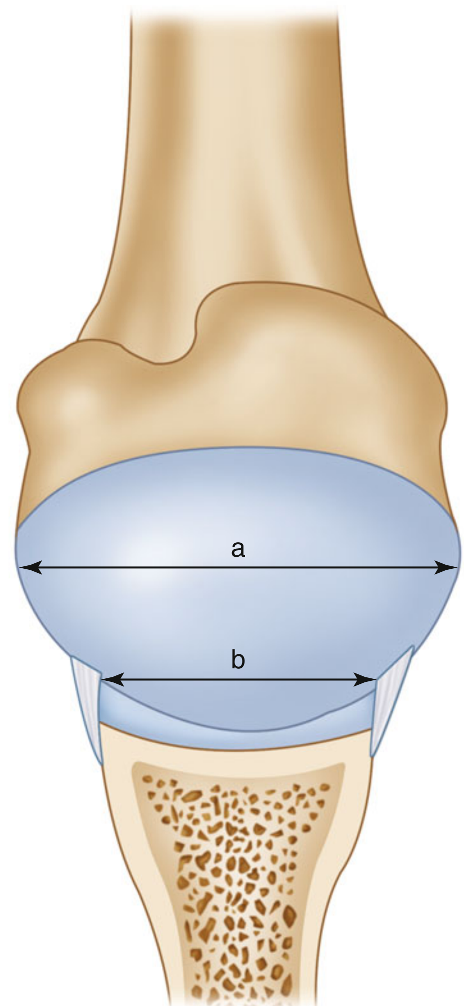

Fig. 2.1 Note the larger humeral head (*a*) as compared to the smaller glenoid articular surface (*b*). The functional structure allows for a large range of motion while the humeral head is maintained in the glenoid fossa by a combination of the dynamic and static stabilizers. Translation of more than one half the sum of the distances of humeral head axis (*a*) and glenoid fossa (*b*) will result in dislocation

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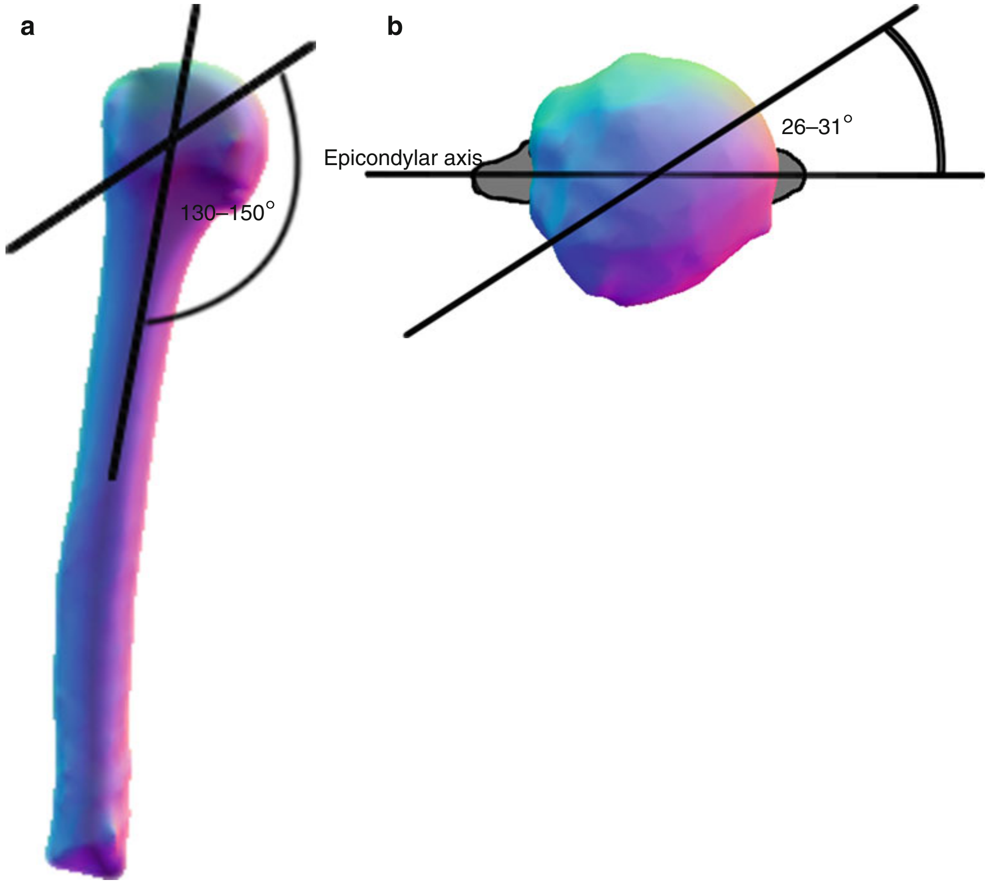


Fig. 2.2 The inclination and version of the humeral head is 130–150° and 26–31°, respectively. Inclination is measured as the angle between humeral shaft and the articular surface of the humeral head in the coronal plane (**a**). Version is measured as the angle between the epicondylar axis distally and the articular surface of the humeral head in the axial plane (**b**)

passive and active stabilizing mechanisms prevent such translations. As the shoulder changes position, different structures are responsible for stabilizing the GH joint. Damage to various anatomic structures can produce shoulder instability through different mechanisms. For example, the mechanics of atraumatic multidirectional instability are usually very different from those of posttraumatic unidirectional anterior instability [5, 7, 11–15].

Anatomy

Humerus

The humerus is the longest bone of the upper extremity and its articulating surface is a hemisphere. The head is inclined relative to the shaft at the anatomical neck at an angle of 130–150° and is retroverted 26–31° from the coronal plane defined by the epicondyles distally (Fig. 2.2). The insertion of the rotator cuff is a continuous crescent interrupted by the bicipital groove, through which the long head of the biceps brachii passes laterally and distally from its origin on the superior aspect of the glenoid [16–19].

Scapula

The scapula forms the posterior aspect of the shoulder girdle and lies atop the posterolateral thoracic cage from ribs 2 through 7. It is a flat, triangular bone with two large surfaces, excluding the articular surface. The glenoid fossa is the bony articulating surface for the humerus, and the superoinferior inclination of the glenoid fossa, known as glenoid tilt, is an important contributor to GH stability [20, 21].

The inclination and version of the glenoid is based upon the medial border of the scapula where it intersects the scapular spine (Fig. 2.3). Normal version ranges from 3° to 11° of retroversion with an average of 7° of retroversion with respect to the scapular plane [22, 23]. Retroversion is associated with anteroposterior stability, while anteversion of more than 5° is found in the majority of unstable joints. However, retroversion of more than 15° is associated with posterior instability. Normal inclination ranges from 7° to 15.8° with an average of 4.2° of superior angulation [24]. This inclination angle is particularly important in preventing inferior translation of the adducted shoulder [11, 23, 25, 26].

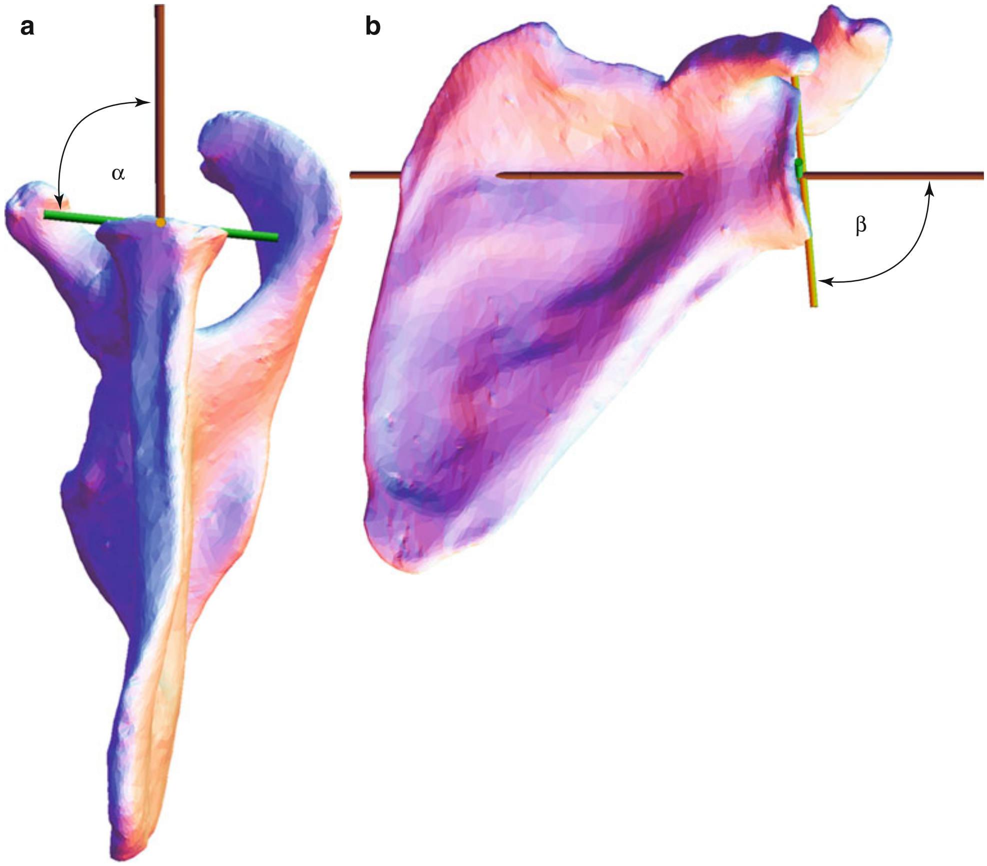


Fig. 2.3 The version and inclination of the scapula is 3–11° and −8° to 16°, respectively. Version is defined as the angle between the line formed by anteroposterior glenoid rim and the line perpendicular to the line formed by the center of the glenoid to the medial border of the scapula at its intersection with the scapular spine in the axial plane (**a**). Inclination is measured as the angle between the line formed by the superoinferior glenoid rim and the line perpendicular to the line formed by the center of the glenoid to the medial border of the scapula at its intersection with the scapular spine in the coronal plane (**b**)

Clavicle

The clavicle is a strut connecting the axial skeleton to the shoulder girdle via the sternoclavicular joint medially and the acromioclavicular joint laterally. The acromioclavicular joint is a diarthrodial joint between the lateral border of the clavicle and the medial edge of the acromion. The clavicle acts as a strut with the axial load transferred to this articulation, which may explain why this joint is often subject to early degenerative changes, especially in people consistently applying high loads.

Scapulothoracic Articulation

The scapulothoracic articulation increases effective arm elevation beyond the 120° of the GH joint. On average, there are 2° of GH elevation for every 1° of scapulothoracic elevation, although the ratio varies within different parts of the arc of motion. The serratus anterior, which maintains the medial angle against the chest wall, and the trapezius, which rotates and elevates the scapula in concert with GH motion, are the two most significant muscles that act upon the scapula [27–30].

Passive Stabilizers

Most investigators attribute a significant passive stabilizing effect to the joint capsule with its discrete ligamentous reinforcements, negative intra-articular pressure, elasticity of the rotator cuff tissue, and fibrous labrum. Indeed, many surgical procedures for the treatment of shoulder instability have been directed at repairing or reconstructing the chock-block of the glenoid labrum and GH joint capsule [31–38]. Differences in capsuloligamentous tension affect translation of the humerus on the glenoid in varying positions of the arm. The GH ligaments are lax in the mid-ranges of rotation. Instead, stability is afforded by a concavity-compression mechanism in which the convex humeral head is compressed into the matched concave articular surface of the glenoid by the shoulder musculature, negative intra-articular capsular pressure, and adhesion-cohesion forces [39, 40].

Articular Surface

The glenoid articular surface is pear-shaped with the anteroposterior width of the inferior half about 20 % larger than the width of the superior half. The glenoid is narrower and approximately half as deep along its anteroposterior axis compared to its superoinferior axis [41]. The articulating surfaces of the normal humerus and glenoid are nearly spherical, and the two contacting cartilage surfaces have very similar radii of curvature. The GH joint can be modeled as a shallow ball and socket configuration with only small translations of the humeral center of rotation relative to the glenoid at the extremes of motion. Therefore, contact on the glenoid articular surface remains relatively constant, whereas contact on the humeral head is focal and changes according to arm position [13, 14, 41–47].

With its hemispheric humeral head and shallow glenoid articular surface, the GH joint is designed for mobility. At any position, only 25–30 % of the humeral head is in contact with the glenoid fossa. Despite the lack of articulating surface coverage, however, the humeral head moves only 1–2 mm within the center of the glenoid cavity throughout the GH range of motion [17, 48, 49].

Using radiographs to evaluate the radius of curvature of the articular surfaces of the glenoid and humerus does not reflect the true congruity of the GH joint, as the average difference of the bony radii of curvature is more than 30 % or 8 mm [40]. In fact, the articular cartilage at the periphery of the glenoid is thicker than it is centrally, which establishes a highly congruent GH joint surface [40, 50]. Generally, the glenoid and humeral radii of curvature differ by less than 10 %, or within about 2.5 mm of a 25.5 mm radius of curvature [43]. The resultant articular conformity is the foundation for the concavity-compression effect of the shoulder musculature and also serves to restrict translation under physiologic loads to within 2.5 mm in all directions [43, 44].

Negative Intra-articular Pressure

The normal GH joint is fully sealed by the capsule and contains less than 1 mL of synovial fluid. Adhesion and cohesion forces act upon the highly conforming GH joint to impart some resistance to the separation of the glenoid from the humerus [39]. Venting the capsule leads to a significant increase in inferior translation in the adducted shoulder, an effect more apparent in shoulders with a small superior glenohumeral ligament [51]. In experiments, venting the capsule also increases instability by decreasing the amount of force required to translate the humeral head by an average of 55 % for anterior forces, 43 % for posterior forces, and 57 % for inferior forces [39]. It has also been shown that in healthy, stable shoulders, intra-articular pressure decreases with increasing humeral translation, while in unstable shoulders, there is no correlation between intra-articular pressure and humeral head translation. In the unstable shoulders, a Bankart lesion—defined as an injury to the anterior glenoid labrum due to anterior shoulder dislocation—was present [38, 52, 53]. The association was made between an intact labrum and maintenance of intra-articular pressure [54]. However, the passive mechanisms of negative intra-articular pressure, articular congruity, and adhesion-cohesion cannot prevent GH instability at high loads by themselves.

Glenoid Labrum

The labrum is a fibrous structure, triangular in cross section, and firmly attached to the circumference of the glenoid rim. At its attachment on the superior portion of the glenoid, it is redundant and can appear loose, whereas the inferior attachment is tight and smoothly transitions from articular surface to labrum. Therefore, mobility of the labrum above the superoinferior midpoint of the glenoid is normal and variable, whereas mobility below the midway point on the glenoid is abnormal and pathologic [41, 55]. Effectively, the labrum deepens the glenoid socket an average of 9 and 5 mm in the superoinferior and anteroposterior planes, respectively, and the traumatic loss of the integrity of the labrum decreases resistance to translation by approximately 20 % [42, 45, 55]. Loss of labral integrity not only decreases the effective depth of the glenoid but loosens the anchor point of various capsuloligamentous structures. Given the labrum's direct and indirect contributions to stability, Bankart deemed the avulsion of the labrum from the anteroinferior glenoid rim, the "essential lesion" responsible for recurrent anterior dislocations [56]. Here, the labrum is separated from the glenoid rim, and the inferior and middle glenohumeral ligaments, which are firmly attached to the labrum at that point, are also avulsed. Surgical intervention is designed to repair this important structure [56, 57]. However, the superior labrum and its biceps origin should not be ignored. Their importance to stability has been shown, as increased anteroposterior and superoinferior translation in the lower and middle ranges of elevation occurs with injury to these structures [58–60].

Joint Capsule

The joint capsule allows for extensive range of motion and therefore has a much larger surface area than the humeral head. Because the resting position of the arm is next to the body, it is the inferior joint capsule that is usually described as redundant to allow for significant abduction and elevation [61]. At the extremes of motion, different parts of the capsule will become taut. For example, the inferior pouch tightens in abduction and external rotation, thus affording joint stability. Also, the anterior translation of the humeral head is minimal in extreme internal rotation, which seems to be an effect produced by tensioning the posterior capsule [3, 62, 63]. The varying tension on different parts of the capsule and the

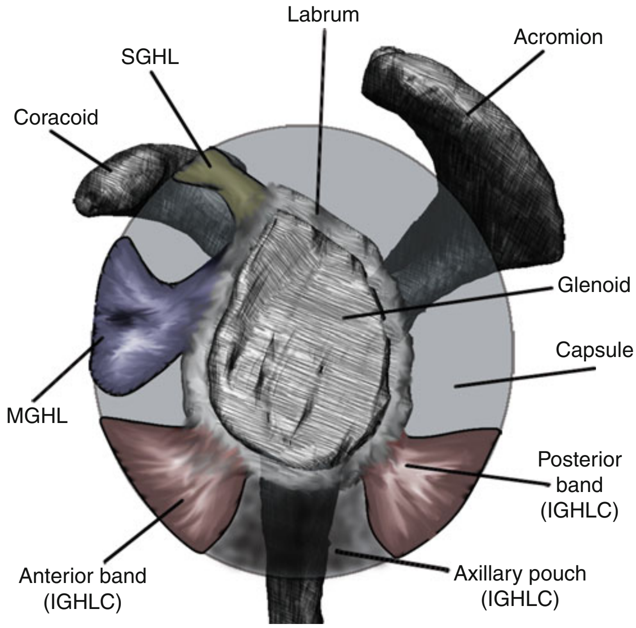


Fig. 2.4 The inferior glenohumeral ligamentous complex (*IGHLC*) is the most important static stabilizer at the extremes of motion. It is formed by the anterior band, axillary pouch, and posterior band. Contributions from the capsule, superior glenohumeral ligament (*SGHL*), and middle glenohumeral ligament (*MGHL*) are also important for anterior, posterior, and inferior stabilization

stabilizing ligaments are functions of their geometry and the position of the arm. In fact, the capsule and GH ligaments constitute a continuous fibrous membrane anatomically, and their mechanical properties are inherently associated [64–66]. In the mid-range of rotational motion, the capsuloligamentous structures are lax, and stability is achieved by other passive and dynamic mechanisms. At the end points of motion, the ligaments become taught and stabilize the joint, and are generally the most significant force preventing translation [1, 15, 43, 61, 67–72].

Glenohumeral Ligaments

The superior glenohumeral ligament (SGHL), middle glenohumeral ligament (MGHL), inferior glenohumeral ligament (IGHL), and coracohumeral ligament (CHL) are thickenings of the GH joint capsule. They are the predominant capsuloligamentous structures responsible for joint stability at the extremes of motion. No single one of these structures stabilizes the GH joint in all positions, and their importance in stability varies with arm position (Fig. 2.4) [1, 11, 15, 18, 19, 27, 42, 43, 49, 61–64, 68–70, 72–77].

The CHL is a thick band of capsular tissue which originates from the base of the lateral coracoid and inserts into the lesser and greater tuberosities. This ligament tightens with the arm in adduction. The CHL and SGHL prevent inferior translation in adduction and posterior translation in forward flexion, adduction, and internal rotation. Some studies suggest that the CHL is important in a suspensory role, but other studies claim that these findings may be inaccurate as the SGHL may have been inadvertently cut while sectioning the CHL. This could lead to the conclusion that the CHL is important in preventing inferior instability when it may not be [1, 15, 43, 78].

The SGHL has a similar function to the CHL and it runs a similar anatomic course. The SGHL extends from the anterosuperior edge of the glenoid to the top of the lesser tuberosity. Together, these ligaments define the rotator interval corresponding to the anterior border of the supraspinatus and the superior border of the subscapularis. While the function of the rotator interval is not clearly defined, it has been suggested that it is important in maintaining negative intra-articular pressure [54, 79, 80].

The structure and properties of the MGHL are the most inconsistent of the three GH ligaments, and it is absent in 8–30 % of people. When present, it originates from the superior labrum, supraglenoid tubercle, or scapular neck and inserts on the medial aspect of the lesser tuberosity. It limits anterior translation of the head in the 60–90° of abduction and inferior translation in adduction. The MGHL and SGHL also prevent anterior translation indirectly by limiting external rotation [4, 61, 81].

The IGHL is the most robust and consistent of the GH ligaments. It has three anatomically distinct regions—an anterior band, axillary pouch, and posterior band. The anterior band is the thickest of the three regions of the IGHL and extends from the anteroinferior labrum and glenoid lip to the lesser tuberosity of the humerus. With the arm in abduction and external rotation, the anterior band moves anterior to the GH joint, its tension increases, and it becomes the primary stabilizer against anterior translation [61, 67, 69, 76].

The anterior band and axillary pouch of the IGHL demonstrate viscoelastic behavior by being stiffer at higher strain rates than at lower strain rates. The proteoglycan content is higher in the anterior band than in the posterior band or axillary pouch. Other biochemical parameters are not statistically different, including water content, collagen, hydroxypyridium crosslinks, and sulfated glycosaminoglycan. The anterior band seems to have the most pronounced fiber bundle interweaving in the mid-substance and insertion sites as compared to the posterior band or axillary pouch [43, 67, 69].

The elasticity of the IGHL varies depending on anatomic region. The IGHL tends to behave elastically in the mid-substance of the ligament, and it behaves viscoelastically near its bony attachments. The anterior band has been shown to accommodate the most strain of the three regions of the IGHL, although all regions demonstrate the ability to sustain significant tensile strain prior to failure [67, 69, 76].

Ligament sectioning studies have shown that at 45° of abduction, the subscapularis muscle, MGHL, and IGHL are the primary GH stabilizers, while at 90° of abduction, the

IGHL is the primary stabilizer. The inferior half of the capsule seems to be more important than the superior half in terms of stability. Sectioning the posterior capsule increases anterior translation during the latter part of abduction. The IGHL and posteroinferior capsule are the primary restraints against anterior dislocation, and the MGHL, when present, is the secondary restraint [4, 61, 81].

In concordance with the ligament sectioning studies, biomechanical strain analysis experiments of the GH capsuloligamentous complex have shown that the IGHL and MGHL show the largest strain at about 45° of abduction, with maximum MGHL strain between 30 and 45°. Similarly, the IGHL distinctly shows the most strain at 90° of abduction. With the arm abducted, the anterior band of the IGHL shows the most strain in external rotation while the posterior band shows the most strain in internal rotation [75, 82]. Some experiments have shown that the SGHL is also important in preventing anterior translation in the abducted, neutrally rotated arm [70]. In all cases, the capsule is a secondary restraint to instability.

Posterior stability is provided by the posterior capsule and IGHL, which have their greatest effect with the arm in abduction, the position in which posterior dislocation usually occurs [83, 84]. Sectioning the posterior capsule, including the posterior band of the IGHL, results in significant posterior translation only with the arm in abduction. However, cadaveric experiments have shown that even with sectioning the posterior capsule, infraspinatus, and teres minor, posterior dislocation will not occur. Additional obliteration of the anterosuperior capsule, including the SGHL, results in posterior dislocation. Sectioning of the anterosuperior capsule and SGHL alone does not result in posterior dislocation. Therefore, it has been suggested that disruption of both the posterior and anterior capsules is necessary to accomplish posterior dislocation (Table 2.1) [3, 63, 70, 85, 86].

Dynamic Stabilizers

Dynamic stabilization is the phenomenon of providing stability to the GH joint through coordinated interactions between muscles that affect it. In general, muscles provide stability through four mechanisms: (1) bulk effect of the muscle itself, (2) contraction causing concavity-compression effect on the articular surfaces, (3) joint motion that secondarily tightens the passive ligamentous restraints, and (4) barrier effect of the contracted muscle [87, 88].

Rotator Cuff and Deltoid

The rotator cuff is a musculotendinous complex that provides stability to the GH joint by compressing the humeral head against the glenoid. Consisting of the supraspinatus, infraspinatus, subscapularis, and teres minor, the rotator cuff muscles originate from the scapula and insert on to the proximal humerus in a radial fashion on its own facet. Specifically, the supraspinatus originates from the supraspinous fossa and inserts on the superior and middle facet of the greater tuberosity. Innervated by the suprascapular nerve, the supraspinatus functions primarily to stabilize the GH joint during abduction of the shoulder, and it secondarily works synergistically with the deltoid as an abductor of the shoulder. The infraspinatus originates from the infraspinous fossa and inserts on the posterior facet of the greater tuberosity. Innervated by the suprascapular nerve, the infraspinatus works with the teres minor to externally rotate the humerus and stabilize the GH joint against posterior subluxation. The teres minor originates from the lateral border of the scapula and inserts on the inferior facet of the greater tuberosity. Innervated by the axillary nerve, it functions as an external rotator and GH stabilizer. Finally, the subscapularis originates from the subscapular fossa and inserts on the lesser tuberosity. Innervated by the upper and lower subscapular nerves, the subscapularis internally rotates the humerus and functions to stabilize the GH joint during abduction. The subscapularis is an important anterior barrier to resist anteroinferior displacement of the humeral head and therefore plays a critical role in GH stability [89, 90] (Fig. 2.5).

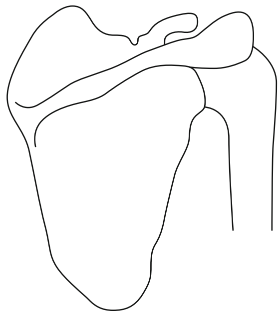
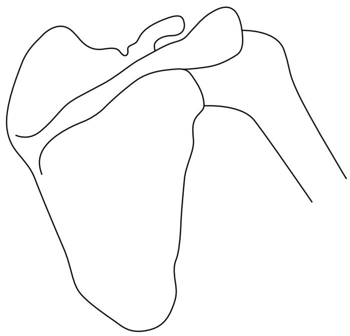
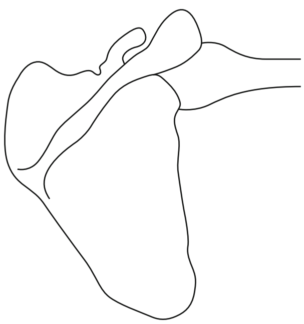
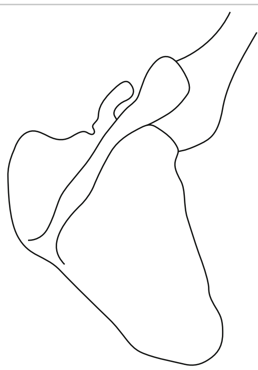
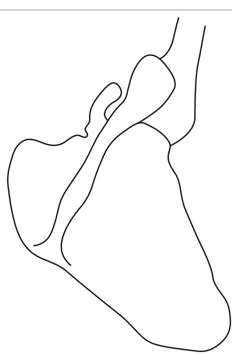
Although static and dynamic factors could potentially operate in all ranges of motion throughout the shoulder, it is thought that the static factors like the capsule and ligaments are primarily responsible at the end-ranges of the shoulder range of motion when under tension. Dynamic factors, like the rotator cuff and deltoid muscles, are primarily responsible in the mid-ranges of the shoulder, when the capsule and ligaments are lax and do not provide any support to the GH joint [11, 91, 92].

The rotator cuff muscles rotate and depress the humeral head during abduction, which is critical for GH stability. The mechanism by which the rotator cuff maintains the humeral head in the glenoid fossa is known as concavity-compression [45, 50]. This is a stabilizing mechanism in which the compression of the humeral head against the glenoid fossa allows for the GH joint to resist shear forces.

The muscle fibers of the rotator cuff primarily run transversely, and the tendons of the muscles form a cuff and surround the joint. They eventually blend intricately with the fibrous capsule. Through its attachments to the capsule, the rotator cuff reinforces the GH joint and functions as an active support structure [42]. The rotator cuff muscles have even been coined "true dynamic ligaments" [93]. Agonistic and antagonistic muscle groups must have coordinated muscle contractions to maintain a stable shoulder joint during movement [8, 11, 45, 94].

Each of the dynamic stabilizers contributes to GH stabilization at different angles of abduction (Table 2.1).

Table 2.1 The primary and secondary stabilizers of the glenohumeral joint during shoulder abduction with neutral rotation

		Anterior stability	Inferior stability	Posterior stability
Rest		Primary: supraspinatus Secondary: SGHL and MGHL (external rotation); posterior capsule (internal rotation)	Primary: superior capsule[a], CHL[a], SGHL[a], supraspinatus, biceps brachii Secondary: proximal 1/3 of anterior capsule (including SGHL and MGHL)	Primary: posterior capsule
0–45°		Primary: subscapularis, MGHL, IGHL	Primary: IGHL, MGHL	Primary: posterior capsule, IGHL
45–90°		Primary: IGHL, posterior-inferior capsule, biceps brachii (internal rotation), rotator cuff muscles, deltoid Secondary: MGHL	Primary: IGHL, MGHL	Primary: posterior capsule, IGHL, biceps brachii (external rotation)
90–135°		Primary: IGHL, axillary pouch, subscapularis, infraspinatus	Glenoid inclination	Primary: posterior capsule, IGHL
135–180°		Primary: IGHL, axillary pouch, Infraspinatus	Glenoid inclination	Primary: posterior capsule, IGHL

[a]The roles of the superior capsule, CHL, and SGHL in inferior stability are inconclusive

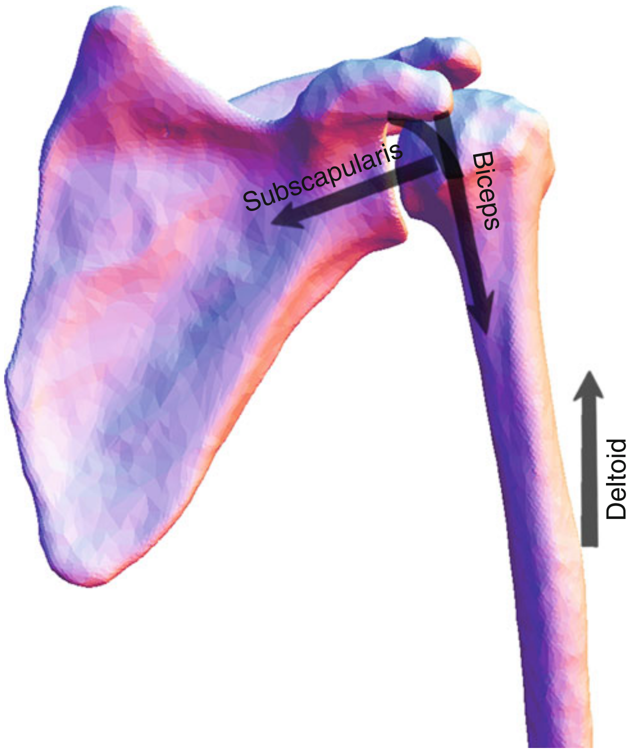


Fig. 2.5 The subscapularis is a major active stabilizer of the shoulder, and its location just anterior to the glenohumeral joint allows it to act as a major anterior stabilizing structure of the humeral head

At Rest

With the arm at the side, the weight of the arm pulling downward is counteracted, and the humeral head is sustained in the glenoid fossa by an isometric contraction by the supraspinatus muscle. This muscle produces the appropriate amount of tension by a spindle system which has motor and sensory fibers connected to the spinal cord [95].

Initial Movement

It has generally been accepted that the synergy of the rotator cuff and the deltoid is required for strong shoulder abduction. When its fibers contract simultaneously, the deltoid abducts the arm along the frontal plane. However, the deltoid does not function to abduct the arm at the initiation of the movement. When the humerus is at 0° of abduction, the deltoid's force of action is nearly vertical. This isolated force would cause upward translation of the humerus and impingement of the soft tissue between the humeral head and acromion [88, 96, 97]. The infraspinatus, subscapularis, and teres minor pull the humerus at the glenoid in a downward direction, which work to compress the humeral head and counterbalance the upward force produced by the deltoid (Fig. 2.6) [7, 98].

A study has shown that the deltoid muscle is still able to complete a full range of abduction despite a paralyzed supraspinatus muscle, but the power of abduction against resistance

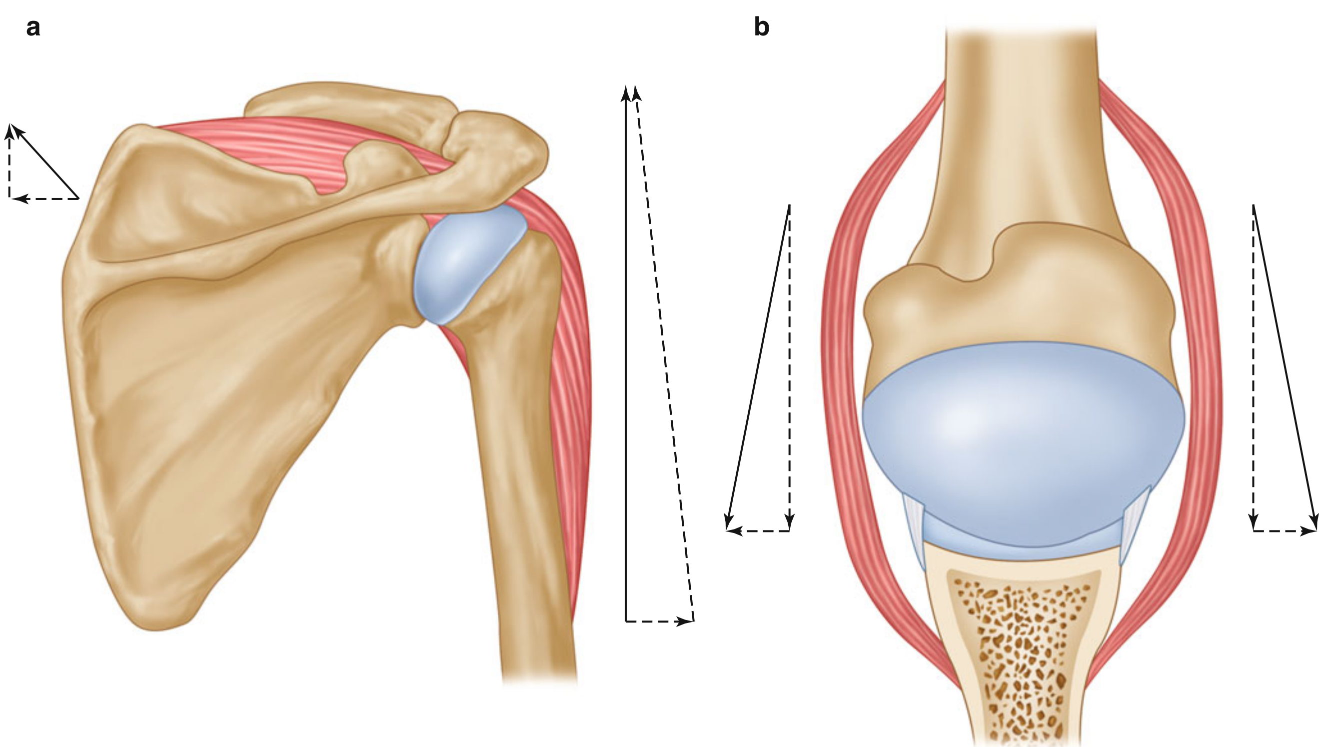


Fig. 2.6 (**a**) The resultant force vectors produced by the deltoid and supraspinatus muscles during abduction. The weight of the humerus is counterbalanced during shoulder abduction by the vertical forces produced by the deltoid and supraspinatus muscles. The supraspinatus also functions to pull the humeral head into the glenoid fossa—a phenomenon known as compressive effect. (**b**) The resultant force vectors produced by the subscapularis and infraspinatus muscles during abduction. Similar to the supraspinatus muscle, the subscapularis and infraspinatus muscles compress the humeral head into the glenoid fossa thereby stabilizing it

is consistently lower. The role of the supraspinatus muscle is to assist the deltoid in abduction to 90° and to stabilize the humerus to allow greater functional strength and stamina of the deltoid muscle [8, 9, 99].

At 0° of abduction, the subscapularis is largely responsible for shoulder joint stabilization, with smaller contributions from the infraspinatus and teres minor [61]. This counteracting force prevents the upward translation of the humeral head and secures it in place during the initiation of shoulder abduction. This phenomenon is an example of force coupling—a sum of forces produced by a group of muscles with differing force vectors resulting in a net moment distinct from the line of action of any one muscle [88, 93].

Midrange Movement

At 45° of abduction, the subscapularis muscle, along with the MGHL and IGHL, continues to bear the primary role of supporting the shoulder [61]. As abduction of the shoulder increases and approaches 90°, the role of the subscapularis and infraspinatus progressively increases. At 90°, the deltoid directs a large part of its force towards the glenoid, which results in the compression of the humeral head against the glenoid. In addition, the rotator cuff muscle fibers are oriented more transversely which, when combined with the forces produced by the deltoid, produce a tremendous compressive force on the humeral head through the glenoid. As abduction continues from 60° to 150°, the power of the subscapularis and the infraspinatus continues to rise [23].

Electromyographic (EMG) activity of the shoulder muscles in patients with generalized joint laxity shows that the activity of the subscapularis muscle is low and the activation speed is slow. The decreased subscapularis muscle activity presumably contributes to the joint instability [100]. Conversely, other studies have observed increased EMG activity of the subscapularis and supraspinatus in patients with generalized joint laxity. The increased subscapularis muscle activity is thought to compensate for capsuloligamentous laxity [101]. Overall, the role of the subscapularis muscle has generally been accepted to stabilize the shoulder anteriorly with the arm in abduction and neutral rotation. It becomes less important with external rotation, in which position the posterior cuff muscles reduce anterior strain.

End-Range Movement

As abduction of the humerus continues past 150°, the power of subscapularis shows a rapid decline, but the power of the infraspinatus continues to rise from 150° to 180° [23]. In the upper ranges of elevation, the axillary pouch of the IGHL stabilizes and supports the GH joint.

Biceps Brachii

The long and short heads of the biceps muscle are contributors to dynamic stability of the GH joint [9, 58, 102–104]. They are particularly important in the stabilization of both anterior and superior translation of the humeral head. The long head of the biceps originates from the superior glenoid labrum, and the tendon travels within the joint and anteriorly on the humerus through the bicipital groove. Like the rotator cuff, the long head of the biceps tendon lies in close proximity with the GH joint, making it anatomically ideal to act as a dynamic shoulder stabilizer. It is important to note the direction of the long head of biceps tendon force is considered two components—one perpendicular and the other transverse to the glenoid surface [58]. The effectiveness of the long head of the biceps in stabilizing the GH joint depends on arm position. The short head of the biceps originates from the coracoid process and travels along the humerus and joins the long head of the biceps to form the biceps brachii muscle.

The roles of the short and long heads of the biceps in anterior stability are particularly important when the arm is in abduction and external rotation [9, 58, 102–104]. The compressive effect and barrier effect of the long head of the biceps depend on joint orientation which determines the line of action of the biceps tendon. At neutral rotation, the tendon lies in a slightly anterior position. With internal rotation, the tendon lies anterior to the joint. With external rotation, it lies posteriorly. Therefore, the observed anterior stabilization offered by the biceps occurs when the arm is internally rotated and posterior stabilization occurs when the arm is externally rotated [58, 105]. The stabilizing effect of the biceps is largest in the lower and middle abduction angles. The short head of the biceps tendon, however, works as a GH stabilizer through a different mechanism—it functions primarily as a physical barrier to prevent anterior translation of the humeral head. The short head of the biceps always lies anterior to the humeral head and therefore prevents excessive translation of the humeral head when it moves anteriorly and comes into contact with the tendon (Fig. 2.7) [58, 105].

One study explored the relationship between the passive stabilization of the IGHL and the active stabilization by the biceps tendon. When the arm was placed in abduction and external rotation, the most vulnerable position for anterior dislocation, the transection of the long head of the biceps tendon resulted in an increase in IGHL strain. This increase in ligament strain could presumably contribute to instability. It was postulated that the long head of the biceps tendon maintains GH joint stability by resisting torsional forces on the humerus and that it does so by acting as an internal rotator in abduction and external rotation [106].

The role of the biceps in the shoulder is still controversial. Some studies claim that the long head of the biceps acts as a shoulder flexor and abductor, while others claim it works to externally and internally rotate the humerus [60]. It is thought that the biceps serves to dynamically stabilize the GH joint, particularly in humeral abduction and external rotation. The role of biceps in stabilization increases as GH joint stability decreases [60].

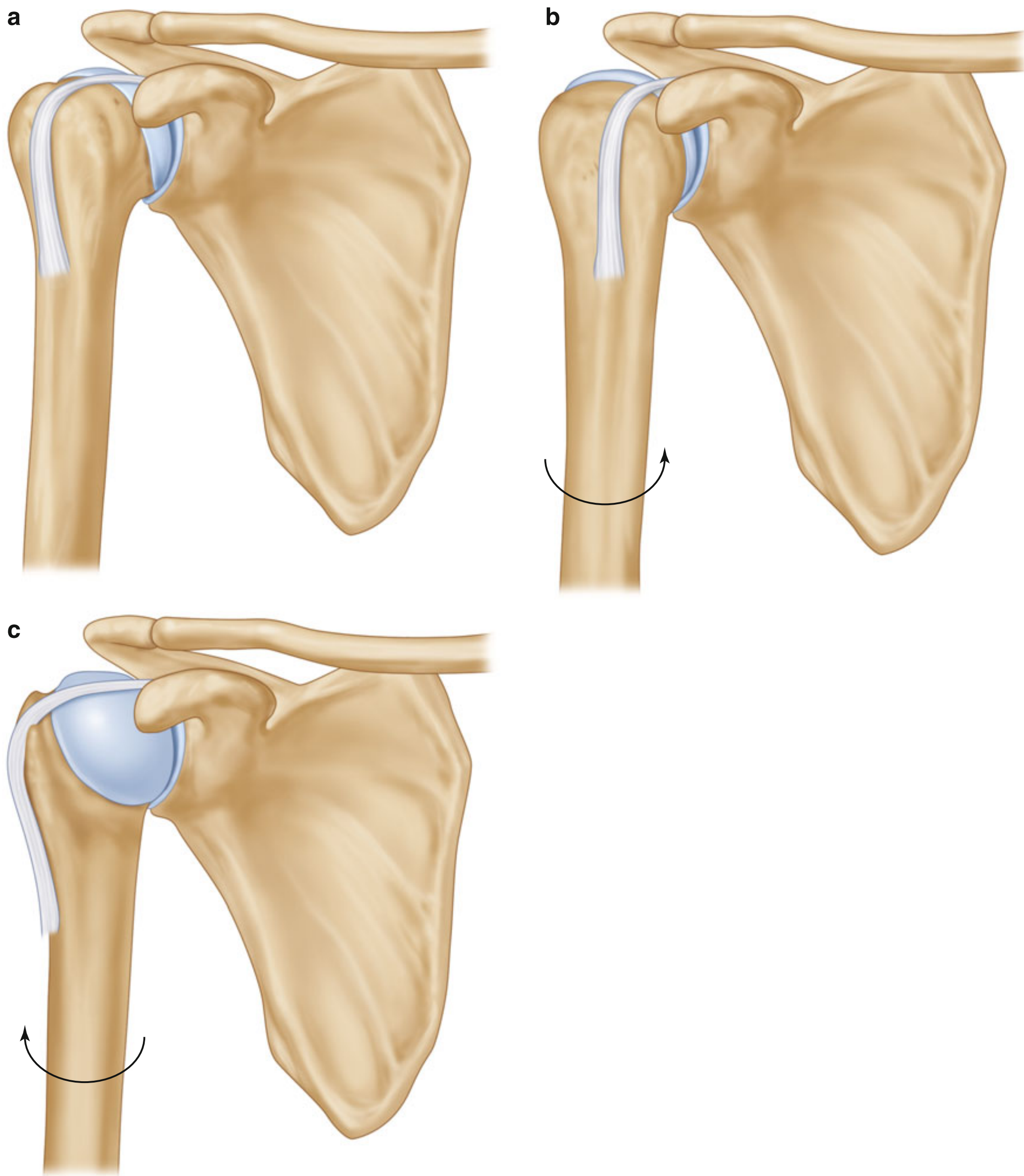


Fig. 2.7 The relationship between the long head of the biceps and the humeral head in neutral (**a**), internal (**b**), and external (**c**) rotations. Note as the humerus is internally rotated, the long head of the biceps lies in an anterior position, thereby restraining anterior humeral head translation. Conversely, the long head of the biceps acts as a posterior stabilizer when the humerus is externally rotated

Scapula

The scapula itself serves four functions: (1) provides a receptacle for the humeral head, (2) connects the body and the arm, (3) serves as a base for muscle attachment, and (4) orients the glenoid to increase range of motion available to the upper limb and thereby increases mobility [107]. The scapular rotators ensure the proper positioning of the scapula, which is crucial to optimize the length-tension relationship of the muscles for shoulder movement [107]. The scapular plane lies in approximately 35° of anteversion in relation to the coronal plane of the body [23]. This positioning of the scapula allows it to achieve proper balance of force couples and ensure dynamic stabilization of the shoulder throughout the entire range of motion. In essence, the scapula optimizes the contact between the humeral head and glenoid to ensure stability; mechanical stability is achieved by bringing the glenoid fossa directly under the head of the humerus [23, 96, 107].

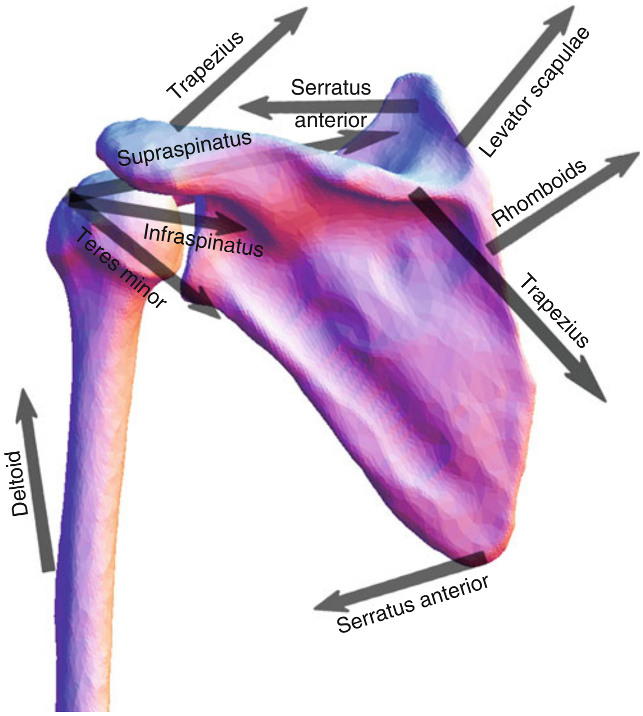


Fig. 2.8 The directions of force produced by the muscles acting on the humerus and scapula. The scapular rotators position the scapula to achieve motions with efficient biomechanics to allow for optimum shoulder function. The coordinated movements of the humerus and scapula are essential to provide stability to the glenohumeral joint by keeping the joint angle within a physiological range

Scapula Rotators

The scapular rotators are composed of the trapezius, rhomboids, latissimus dorsi, serratus anterior, and levator scapulae. Force coupling of these muscles is necessary to allow for active range of motion. The upper portion of the trapezius acts on the acromion in a medial direction while the serratus anterior produces a rotary force from the inferior angle of the scapula in a lateral direction [107]. The combination of these two forces rotates the scapula and is responsible for a significant part of total arm elevation . Rotation of the the scapula also allows for full abduction of the arm while avoiding impingement of the acromion upon the rotator cuff [108] (Fig. 2.8).

Glenoid Tilt

The glenoid articular surface primarily rotates in the coronal plane. Therefore, vertical stability does not depend as much on the vertical tilt of the glenoid surface. However, studies have shown the stability of the GH joint increases proportionally with the inclination of the glenoid and the relationship between the slope of the glenoid and the mechanical stability of the GH joint is linear in the posteroinferior direction [26, 109]. Inferior stability increases with a superior tilt of more than 10° [26]. In rare cases where excess inferior tilt of the glenoid leads to vertical instability, patients can often voluntarily dislocate their GH joint downward [23].

Scapulohumeral Rhythm

Scapular motion is particularly important during shoulder abduction and flexion. This motion is known as scapulohumeral rhythm [93]. Measurement of this motion shows that the ratio of GH movement to scapulothoracic movement is 2:1 during abduction. As the GH joint abducts, the scapula rotates upward to allow for full arm elevation and to maintain a position of stability.

The ability to control and coordinate the movement of the scapula in relation to the humerus is essential for stability of the GH joint. Improper movement of the scapula causes misalignment of the humeral head with the glenoid and contributes to shoulder instability [23, 96, 107].

Proprioception

Proprioception is the sense of the relative positions of parts of the body, and it helps to prevent excessive strain in capsuloligamentous structures of the shoulder. It is thought that damage to the soft tissue structures around the shoulder may also disrupt the proprioceptive capabilities of the ligaments, which may contribute to shoulder instability. Previous studies have shown that GH dislocation results in abnormal neuromuscular coordination and increases the likelihood of subsequent reinjury to the shoulder [110]. When comparing individuals with normal, unstable, and surgically repaired shoulders, proprioception is impaired in patients with GH instability. Interestingly, this feedback seems to be restored in surgically repaired shoulders [111].

The proprioceptive feedback mechanism is still not completely understood. Pacinian corpuscles, Ruffini endings, Golgi tendon endings, and other mechanoreceptors have been identified in the glenoid labrum and GH ligaments, which confirms the idea that capsuloligamentous structures of the shoulder have the potential to perceive relative positioning [112]. However, there have not been rigorous studies that qualify the role of proprioception in shoulder stability.

Summary

GH instability represents a broad range of pathology which can involve many anatomic structures. Static stabilizers, including the glenoid labrum, the GH capsule, the three GH ligaments, intra-articular pressure, congruity of the joint surface, and adhesion-cohesion forces, are critical to providing passive stabilization. Dynamic stabilizers which include the rotator cuff, biceps brachii muscle, scapular rotators, and glenoid tilt are all important in active stabilization. The sophisticated movements of the shoulder require the delicate balance between the static and dynamic restraints to maintain stability during movement through a wide range of motion.

Shoulder dislocation is associated with disruption or permanent stretching of the GH capsular ligaments. In elderly patients, dislocation is frequently associated with rotator cuff tears. Muscular dysfunction may predispose to instability which is commonly seen in patients who perform repetitive throwing motions or overhead activities. Conversely, capsuloligamentous instability may result in muscular pathology as stabilizing musculature becomes unable to compensate for disrupted or loose static stabilizers. It is clear, however, that the disruption of the IGHL is the most commonly injured component of the capsule, with tissue disruption ranging from plastic deformation, mid-substance tear, or avulsion of the capsuloligamentous complex from its bony attachment site. GH capsular stretch and the resulting laxity are a key feature of shoulder instability and are a major contributor to recurrent dislocations [43, 74, 91].

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