European Journal of Radiology 68 (2008) 16–24

EJR
EUROPEAN JOURNAL OF RADIOLOGY

www.elsevier.com/locate/ejrad

Shoulder biomechanics

Roberto Lugo, Peter Kung, C. Benjamin Ma [a,*]

[a] *Chief, Sports Medicine and Shoulder Service, University of California, San Francisco, 500 Parnassus Avenue, MU 320W-0728 San Francisco, CA 914143, United States*

Received 8 February 2008; received in revised form 9 February 2008; accepted 19 February 2008

Abstract

The biomechanics of the glenohumeral joint depend on the interaction of both static and dynamic-stabilizing structures. Static stabilizers include the bony anatomy, negative intra-articular pressure, the glenoid labrum, and the glenohumeral ligaments along with the joint capsule. The dynamic-stabilizing structures include the rotator cuff muscles and the other muscular structures surrounding the shoulder joint. The combined effect of these stabilizers is to support the multiple degrees of motion within the glenohumeral joint. The goal of this article is to review how these structures interact to provide optimal stability and how failure of some of these mechanisms can lead to shoulder joint pathology.

Keywords: Shoulder; Biomechanics; Glenohumeral joint

1. Introduction

The biomechanics of the shoulder joint has been an active area of study for many years. The shoulder's ability for multiple degrees of motion is based on the interaction of multiple structures that react to mechanical stimuli and adjust accordingly. The inherent bony stability of the shoulder is not significant, as there is a mismatch between the articulating surfaces of the proximal humerus and the glenoid. The addition of the fibrocartilaginous labrum as well as the presence of a constrained capsule and glenohumeral ligaments adds to the stability of the shoulder. But these static stabilizing structures are further supported by the musculature surrounding the shoulder girdle, providing dynamic stability. The rotator cuff muscles not only act as dynamic stabilizers, but also add to the passive stability of the shoulder due to their location and orientation around the glenohumeral joint. The static and dynamic stabilizers react to the forces applied through the glenohumeral joint to provide stability at different positions during the motion arc. The scapulothoracic joint also provides the shoulder with additional degrees of motion and contributes to the stability of the joint. The combination of these factors produces a biomechanically complex system that has adapted to respond to the needs of the upper extremity. This article will review the anatomy of these structures as well as the relationships that contribute to the stability of the glenohumeral joint. We will also highlight the importance of these structures by discussing how their failure to function adequately can negatively affect glenohumeral joint stability.

2. Bony stability

The bony anatomy of the glenohumeral joint is an important component of shoulder stability [1,2]. The humeral head articular surface is normally retroverted by 30°. A study by Saha et al. noted glenoid retroversion at an average of 7°. On its superior tip, the supraglenoid tubercle is the origin of the long head of the biceps. On its inferior pole, the infraglenoid tubercle is the origin of the long head of the triceps [3,4]. A maximum of 30% of the articular cartilage of the humeral head articulates with the articular cartilage of the normal glenoid at any time, due to the mismatch between the humeral head and glenoid articular surfaces. In a study by Soslowsky and colleagues it was shown that the articular surfaces deviated from each other by an average of 2 mm [5]. Hence, areas of contact vary at different degrees during the motion arc. In abduction, the humeral head is more congruent with the glenoid, the contact area is increased and the pressure is decreased [5].

The shape of the glenoid itself is important for glenohumeral stability. Howell and Galinat reported the average anteroposterior depth of the bony glenoid to be only 2.5 mm, whereas the average superior/inferior depth was 9.0 mm [1]. In addition,

* Corresponding author. Tel.: +1 415 353 7586; fax: +1 415 353 9675.
E-mail address: maben@orthosurg.ucsf.edu (C.B. Ma).

0720-048X/$ – see front matter © 2008 Elsevier Ireland Ltd. All rights reserved.
doi:10.1016/j.ejrad.2008.02.051

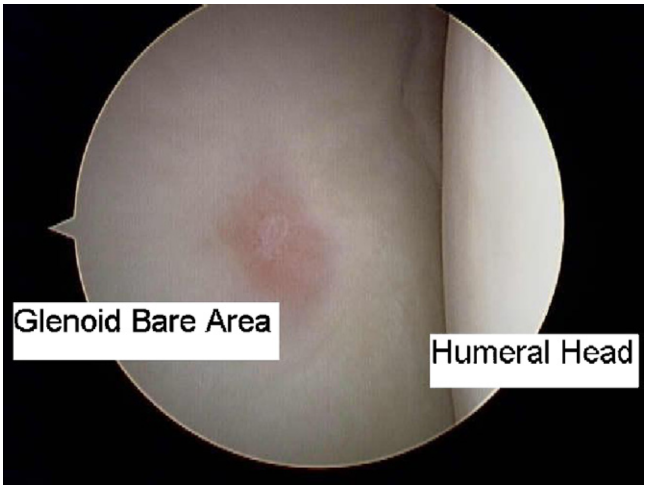

Fig. 1. Bare area of glenoid.

anatomic studies have shown that there is an area of thinner articular cartilage at the central portion of the glenoid. This bare area has been termed the tubercle of Assaki after the French anatomist who described it. It is located at the center of a circle defined by the anterior, posterior, and inferior borders of the lower glenoid cavity as can be seen in Fig. 1 [6]. In the adducted position, the radius of curvature of the glenoid is larger than the humeral head radius and hence there is an area of increased contact. This area corresponds to the bare area which has been found to have thickened subcortical trabeculae when compared to the rest of the glenoid [5]. This reinforces the concept of the differing radii of curvature and how they can affect areas of load in the glenohumeral joint. Along with the glenoid and humeral head articular surfaces, the glenoid labrum adds depth to the glenoid cavity (by 50%) and its contribution will be discussed in the following sections. The increased depth of the glenoid and the compressive forces that stabilize the humeral head have been called "concavity compression" [7].

Another contribution to shoulder stability provided by the glenoid and humeral head articulation is by maintaining a relatively constant capsule volume and ligament tension. Studies have shown that maintenance of negative intra-articular pressure in a closed system can help prevent excessive translation [7]. Disruption of the normal anatomy of the glenoid can disrupt glenohumeral joint stability. Itoi et al. described that bone loss of more than 21% of the superior–inferior glenoid length would cause instability despite correct soft tissue repair [6,8]. Burkhart suggested that loss of 25% of anterior glenoid should prompt for surgical stabilization [6,9]. Disruption of the normal anatomy of the humeral head, as seen with a Hill–Sachs lesion, can further exacerbate instability by engaging with the anterior glenoid during episodes of subluxation or dislocation of the glenohumeral joint. If the lesion comprises 25% or more of the humeral head, bone grafting is usually recommended. See Fig. 2 for a depiction of an anterior locked shoulder dislocation with large Hill Sachs lesion.

Although the bony anatomy and articulation of the glenohumeral joint are important for stability, the addition of the glenoid labrum as well as static and dynamic stabilizers to the shoulder biomechanics contribute to a complex interaction to produce stability through the joint.

3. Muscular stability

3.1. Scapulothoracic muscles

The stability of the glenohumeral joint is also affected by the large muscles acting away from the shoulder joint itself. The latissimus dorsi, serratus anterior, pectoralis major, and deltoid can generate large torques about the shoulder joint due to their cross-sectional anatomy and distance from the joint center of rotation. The scapulothoracic articulation comprises a space between the surface of the posterior thoracic cage and the surface of the anterior scapula [10]. The neurovascular, muscular, and bursal structures allow smooth motion of the scapula on the thorax. The scapula is the origin or site of insertion for seventeen muscles. Important muscles that contribute to scapulothoracic motion include the trapezius, the levator scapulae, the rhomboids, the serratus anterior, the pectoralis minor and the subclavius. The most important of these muscles are the serratus anterior, which maintains the medial angle against the chest wall, and the trapezius, which helps to rotate and elevate the scapula in synchrony with glenohumeral motion. Deficiencies of these muscles can cause different types of winged scapulae.

Scapular motion is based on its orientation, which is internally rotated by 30°, abducted 3°, and tilted anteriorly by 20°. The scapula moves in different planes to produce a combination of movements that culminate in protraction or retraction [4]. For everyday activities, scapulothoracic motion provides only 15° of internal rotation. If the scapula is fused, limitation occurs mostly with extension and internal rotation [4]. The

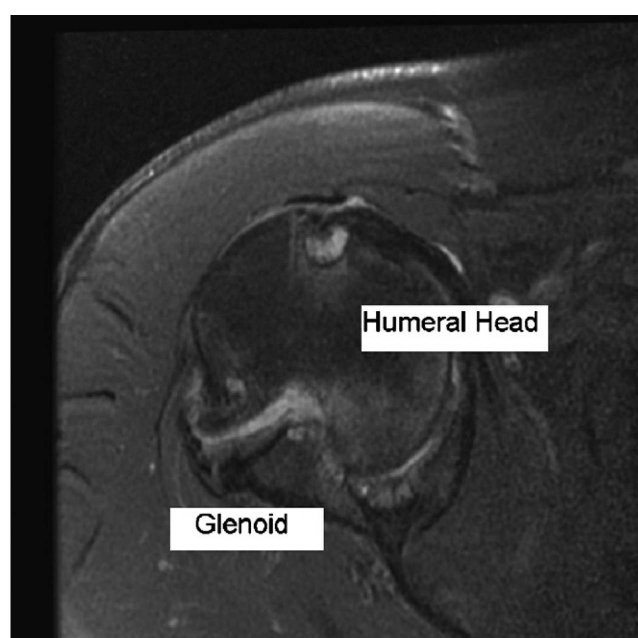

Fig. 2. Anterior locked shoulder dislocation with large Hill Sachs Lesion.

scapulothoracic articulation allows increased shoulder movement beyond the initial 120° provided by the glenohumeral joint [10]. The coordinated movement between the scapulothoracic joint and the glenohumeral joint has been termed the scapulothoracic rhythm [4]. Inman, et al. estimated the ratio between glenohumeral and scapulothoracic joint motion to be approximately 2:1. Shoulders with multidirectional instability have an increased ratio whereas shoulders with impingement or rotator cuff tears tend to have a decreased ratio [4,11].

Disruption of the normal scapulothoracic rhythm can predispose patients to glenohumeral joint pathology. A study from the Kerlan–Jobe clinic demonstrated that weakness of the serratus anterior and/or the subscapularis predispose to the development of rotator cuff tendinitis symptoms in young baseball pitchers [12]. Symptoms consistent with impingement and rotator cuff tendinitis develop due to the deranged orientation of the coracoacromial arch, forcing the rotator cuff muscles between the greater tuberosity and the acromion during the motion arc. If left unchecked, atraumatic shoulder instability can develop. Based on these and other findings, scapulothoracic stabilization by strengthening the large scapular rotators has become an important component of physical therapy and rehabilitation for patients with rotator cuff tendinitis, especially younger patients [13].

3.2. Rotator cuff muscles

The rotator cuff muscles are well positioned to resist glenohumeral shear stresses. As will be discussed later, they are located closer to the center of joint rotation and act in association with the underlying capsular ligament structures. Individual rotator cuff muscles have independent actions that in combination contribute to the overall stability of the glenohumeral joint during mid- and end-ranges of motion. Table 1 summarizes the actions of the individual rottator cuff muscles and Fig. 3 shows an illustration of their orientation in space [4]. The role of the rotator cuff muscles in glenohumeral dynamic stability will be discussed in depth in a later section.

The rotator cuff can be considered a fine control muscle system, adjusting through neuromuscular feedback from the forces generated during the motion arc and by feedback from the glenohumeral ligaments. By virtue of this fine control, the cuff muscles also act as pretensioners or cotensioners for the capsular ligaments. The subscapularis, an internal rotator when concentrically contracted and a decelerator of external rotation when eccentrically contracted, cotensions the inferior glenohumeral ligament complex (IGHLC). That is, it prevents the end point of ligament function from being reached or compromised. This may explain the occurrence of atraumatic instability in pitchers with subscapularis weakness as the IGHLC becomes repeatedly stretched.

The rotator cuff muscles may also produce a compressive force across the glenohumeral joint. By maintaining the humeral head deeper into the concavity of the glenoid, rotator cuff muscles can decrease shear forces and help centralize the humeral head on the glenoid. Organized contraction of the rotator cuff muscles coordinated by mechanoreceptors as well as the concavity compression mechanism can facilitate the antishear function of the rotator cuff musculature.

Another important structure associated with the rotator cuff muscles is the rotator interval (RI). The RI is defined as the tissue between the supraspinatus and subscapularis tendons, it also contains the coracohumeral ligament (CHL), the superior glenohumeral ligament (SGHL), and joint capsule (see Fig. 4). If the RI is deficient, the effect would be inferior instability, mainly due to decrease in intra-articular pressure in internal rotation. In external rotation, it is compensated by the coracohumeral ligament. Harryman et al. demonstrated that open imbrication of the CHL resulted in decreased inferior and posterior translation [14]. Provencher et al. could not reproduce the same results, open or arthroscopically, but did find mild decrease in sulcus (decreased inferior translation) and added anterior stability. The adverse outcome was increased stiffness in external rotation [15].

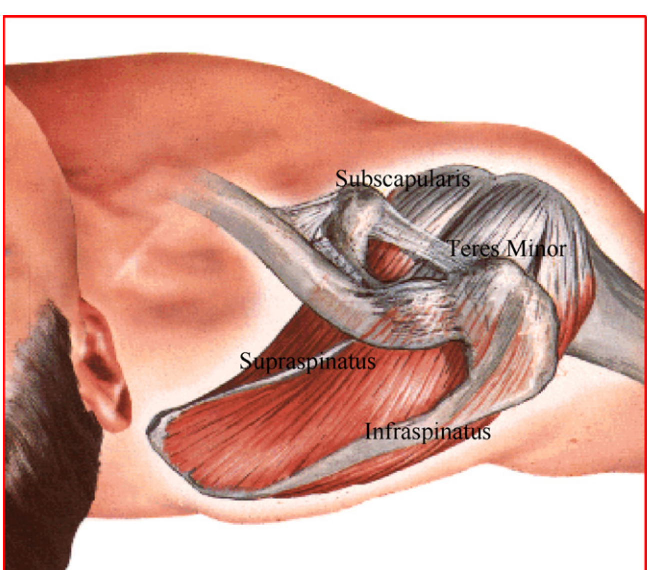

Fig. 3. The rotator cuff muscles.

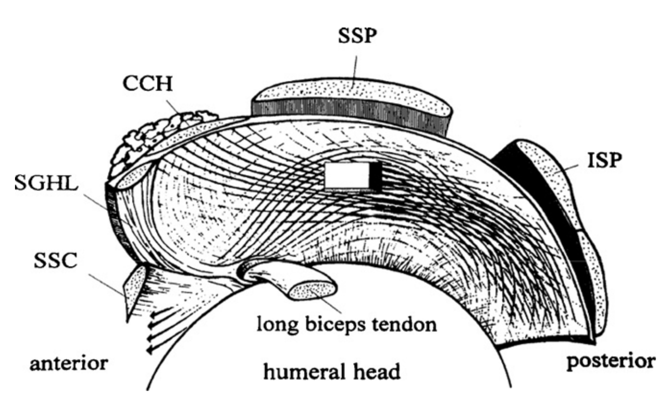

Fig. 4. The rotator interval.

Table 1
The rotator cuff muscles and description of function

Rotator cuff muscle	Description	Action
Supraspinatus	Circumpennate muscle. Average width at midportion of tendinous insertion is 14.7 mm. Mean area of insertion is 1.55 cm^2	Initializes humeral abduction to 90°
		Deficiency can be compensated for by the remaining rotator cuff muscles
Infraspinatus	Circumpennate muscle. Mean area of infraspinatus insertion is 1.76 cm^2	Resists posterior and superior translation Generates 60% of external rotation force
Teres minor	Circumpennate muscle	Resists posterior and superior translation Generates 45% of the external rotation force
Subscapularis	Multicircumpennate muscle	Contributes to the floor of the bicipital sheath Resists anterior and inferior translation Strong internal rotator

4. Ligamentous and labral stability

4.1. Ligaments

The capsuloligamentous complex was initially described in 1829, but its complex interaction continues to be a subject of active investigation. The glenohumeral ligaments can be thought to function as check reins. At the most basic, the glenohumeral ligaments are lax through mid-ranges of motion and become progressively more taut as the end-range of the motion arc is reached. Preservation of this ligamentous integrity is integral in stability during end-ranges of motion. This concept has been found to be accurate with respect to the inferior glenohumeral ligament during traumatic anteroinferior glenohumeral instability, but ligament laxity in the context of chronic instability is more complex.

Each of the glenohumeral ligaments provides stability during a combination of positions throughout glenohumeral joint motion (Table 2 and Fig. 5) [16]. The IGHL is the most frequently injured component of the glenohumeral joint capsule. Tears of the IGHL occur most frequently at its origin or midsubstance, but rarely tears of the humeral insertion of the IGHL can occur. The incidence of this humeral avulsion of the inferior glenohumeral ligament (HAGL, as seen in Fig. 6) has been reported to be as high as 10% and can be a potentially missed diagnosis [17]. The coracohumeral ligament (CHL) resists posterior and inferior translation in the suspended shoulder. The CHL is an inferior stabilizer with the arm in adduction, and it tightens with external rotation. The CHL can withstand three times the tensile load as the SGHL. Fig. 7 presents an arthroscopic view of the SGHL in conjunction with the CHL.

An active area of investigation is how these ligaments interact during complex shoulder motions involving shifts in the centers of rotation or in translation, and how they react suring the middle ranges of motion. Sidles has described the concept of complementary tightening, which no longer assumes ligament function based on tightening of the ligaments or capsular

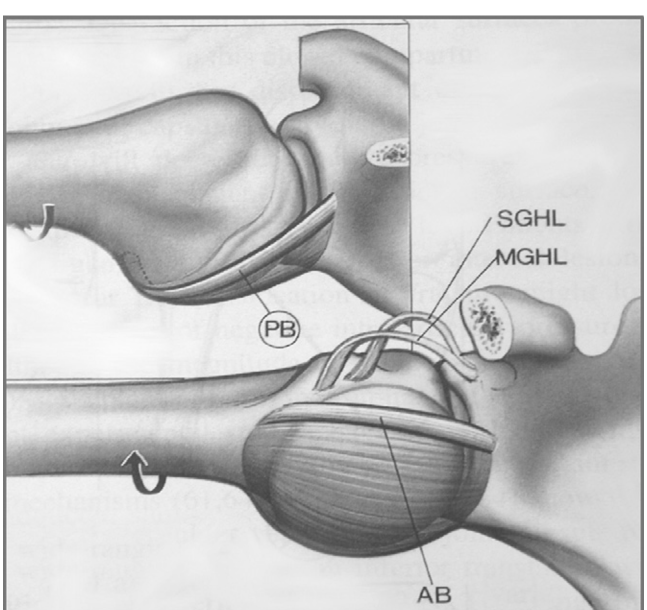

Fig. 5. The inferior glenohumeral ligament. Note as the axillary pouch acts like a “hammock” in the abducted position.

Fig. 6. Humeral avulsion of the inferior glenohumeral ligament (HAGL) (arrow).

Table 2
The glenohumeral ligaments

Glenohumeral ligament	Description	Action
Superior glenohumeral ligament (SGHL)	Originates from the supraglenoid tubercle, anterior to the origin of the long head of the biceps, and inserts on the proximal tip of the lesser tuberosity	Resists inferior translation with the adducted arm in neutral rotation Along with the coracohumeral ligament (CHL), it limits external rotation of the adducted shoulder
Middle glenohumeral ligament (MGHL)	Originates on the supraglenoid tubercle and anterosuperior portion of labrum and inserts onto the lesser tuberosity blending with fibers of the subscapularis tendon	Anterior stabilizer with arm in adduction and up to 30–45° abduction
Inferior glenohumeral ligament complex (IGHLC)	Has three components: an anterior band, an axillary pouch, and a posterior band. The anterior band originates from the anterior labrum and attaches to the glenoid rim. The posterior band is not found in all patients	Resists anteroinferior humeral head translation, especially with the arm in external rotation, abduction, and extension The anterior band tightens with abduction and external rotation of the glenohumeral joint At neutral position (0° abduction and 30° of horizontal extension) the anterior band becomes the primary static stabilizer of the glenohumeral joint The posterior band is the primary static stabilizer with the arm in flexion and internal rotation, providing posterior stability
Coracohumeral ligament (CHL)		Resists posterior and inferior translation in the suspended shoulder Inferior stabilizer with the arm in adduction, and it tightens with external rotation

segments in response to eccentric joint alignment [18]. As an example, the tension developed in the IGHL causes a tightening of the posterior capsular structures to balance the static anterior restraint of the IGHL. This is important in the study of shoulder instability because ligaments acting differently from their coordinated function can further destabilize the injured shoulder.

Karduna et al. described the concept of ligamentous laxity during the mid ranges of motion when the dynamic muscle forces provide the primary stability to the glenohumeral joint [19]. They focused on the origin to insertion function ligament length (wrap length). In external rotation, long wrap lengths of the IGHL were associated with increased passive posterior glenohumeral translation. This motion helps position the humeral head within the glenoid concavity preventing anterior translation. In patients with IGHL deficiency this mechanism no longer counteracts anterior translation of the humeral head on the glenoid. The resulting sensation of anterior subluxation or impending dislocation is the basis for the so-called apprehension sign. The reduction or “relocation” maneuver reduces the humeral head to the proper rotation center location for a given motion [13].

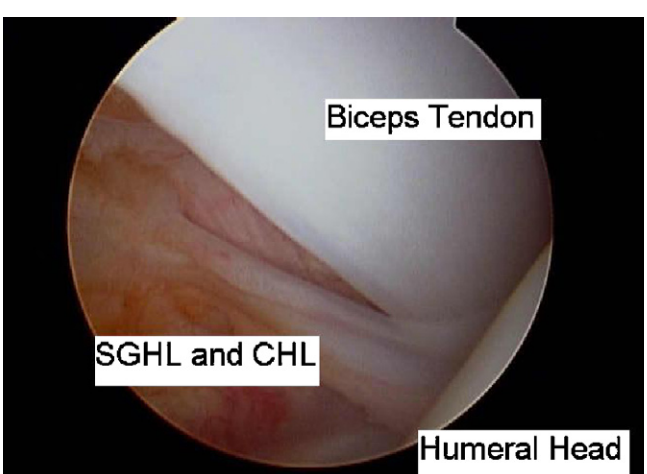

Fig. 7. The superior glenohumeral ligament (SGHL) and the coracohumeral ligament (CHL).

4.2. The glenoid labrum

Matsen used the term glenohumeral joint stability to describe the ability to keep the humeral head centered. The humeral head is compressed into the glenoid labral concavity by the actions of the muscular stabilizers and negative intra-articular pressure. The glenoid labrum is an integral component of this articuation. It is a ring of triangular shape in section overlying the periphery of the glenoid. Its free edge projects into the joint. The base is attached by fibrocartilage and fibrous bone. It blends superiorly with the origin of the long head of the biceps tendon. It functions to deepen the glenoid, increase congruity, generate a suction effect, and enhances stability of the glenohumeral joint. Per Howell and Galinat the glenoid has an average depth of 9 mm in the superoinferior direction and 5 mm in the anteroposterior direction. The labrum contributes 50% of the socket depth [1]. Although the labrum allows for a deeper glenoid concavity, the degree of stability is largely dependent on joint compressive forces, labral compliance, and articular integrity. This concavity compression effect is enhanced by the rotator cuff muscles

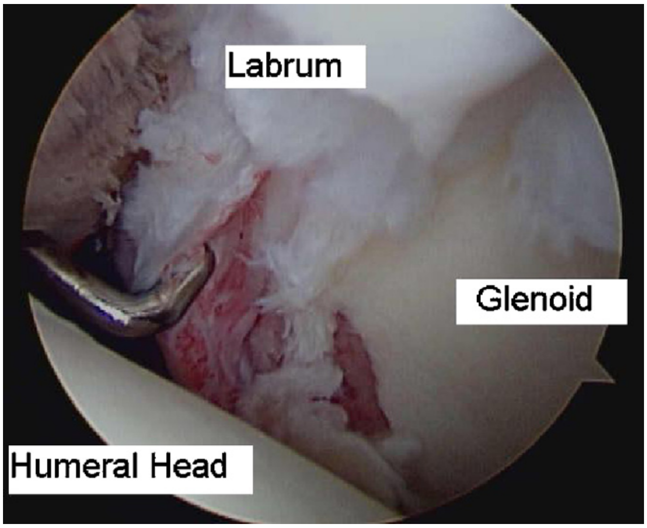

Fig. 8. Bankart lesion.

during mid-ranges of motion when the glenohumeral ligaments are theoretically lax.

The labrum has two primary mechanical functions. The first function is to serve as an attachment site for the glenohumeral ligaments to the glenoid rim. The labrum is contiguous with the glenohumeral ligaments and is distinct from the glenoid, although a few exceptions (including the Buford complex) are evident in anatomic specimens. This histologic and gross distinction is the anatomic basis for the (Fig. 8) Bankart lesion (as seen in Fig. 9), an end-range failure of the IGHLC resulting in avulsion of the anteroinferior labrum from the glenoid [13].

The second mechanical function of the glenoid labrum is to function as an antishear bumper, which is more evident during mid-ranges of shoulder motion. A deeper glenoid labral concavity and higher compressive load increase the resistance to joint subluxation. The slight deepening effect and mobility of the labrum probably serve to help keep the humeral head centered in the glenoid. In a study by Halder, stability through concavity compression with an intact labrum was greater in the hanging arm position than in abducted positions [20]. After resecting the labrum, the investigators detected an average decrease in the stability ratio of approximately 10% throughout all loading directions. The largest effect was observed in the inferior direction. This corresponds with the fact that the inferior glenoid is a fibrous immobile extension of the cartilage. The anterior and anterosuperior aspects of the labrum are more loosely attached. Maximum stability was achieved in the inferior direction with an intact labrum. Without the labrum, there was more stability in the superior direction. This reflects the fact that the glenoid is shaped like an inverted comma with an anterior incision. The deeper glenoid concavity and the bumper effect play a role during different aspects of the glenohumeral joint motion arc. Although the glenoid labrum is important for stability, the rotator cuff muscles can provide enough pressure to assure that concavity compression will work.

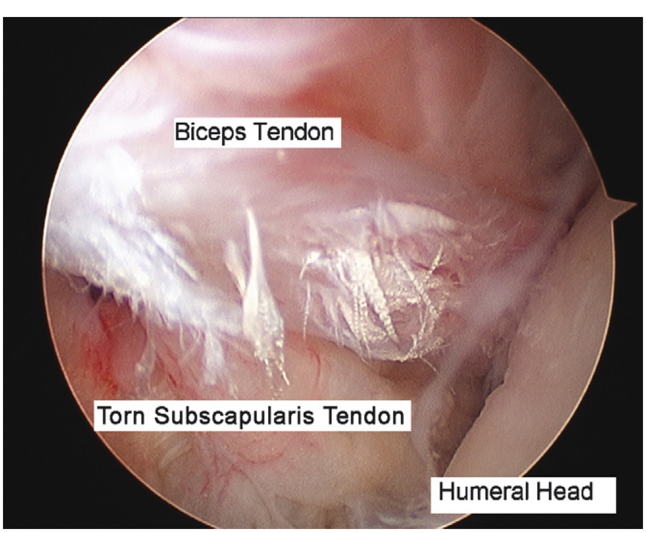

Fig. 9. Dislocated and frayed long head of the biceps tendon. Usually associated with subscapularis tendon tears.

5. The long head of the biceps tendon

The role of the intra-articular biceps tendon in glenohumeral biomechanics continues to be a source of controversy. Historically, the long head of the biceps tendon has been seen as both an active depressor and a static stabilizer of the glenohumeral joint. The biceps functions as an effective humeral head depressor, maintaining proper ligament tension in some of the glenohumeral ligaments as predicted by the complementary tightening concept of shoulder stability. Loss of the biceps induces increased forces in glenohumeral ligaments and is associated with a superior shift in the glenohumeral articular contact point. In patients with rupture of the long head of biceps tendon, the humeral head translates superiorly during abduction [4,21]. Although the biceps has been thought to be a depressor of the humeral head, increased EMG activity of the biceps in anteriorly unstable shoulders during throwing has suggested that the biceps can compensate for glenohumeral joint instability. With loading of the biceps, there is significantly decreased anterior-posterior translation, particularly with external rotation. When artificial Bankart lesions are created, the biceps is more important than any rotator cuff muscle in stabilizing the glenohumeral joint against anterior displacement. Long head of the biceps tendon origin instability and its association with the superior aspect of the glenoid labrum (known as the SLAP lesion) may represent a loss of the effective depressor function from the tendon. Pagnani et al. have found that application of force to the biceps tendon reduced both anterior-posterior and superior-inferior translation, but also observed that it tended to stabilize the joint anteriorly when the arm was in internal rotation and served as a posterior stabilizer when the humerus was in external rotation [22]. Rodosky et al. also found that application of force through the long head of the biceps reduced stress on the IGHLC [23]. The importance of the biceps can also be seen with its hypertrophy in patients with chronic rotator cuff insufficiency. With loss of dynamic stabilizers, the biceps tendon takes on larger stresses, and it reacts accordingly to compensate for the deficiency. In addition, the biceps tendon can often be found dislocated from the bicipital groove in association with subscapularis tendon tears as seen in Fig. 9.

6. Active versus passive stability

6.1. Basis of static stability

The glenohumeral joint is unique because it maintains stability despite its few restraints. These restraints include static and dynamic components. Static stabilizers refer to bony, cartilaginous, capsular, and ligamentous structures. The dynamic stabilizers include the musculature surrounding the shoulder. The glenohumeral ligaments serve as static stabilizers preventing excessive translation of the humeral head, especially in the extremes of motion [21]. The relationship between the static stabilizers of the shoulder can be explained by the circle concept of capsuloligamentous stability, which implies that excessive translation in one direction may require damage to restraints on the same and opposite sides of the joint [21].

In addition, it has been postulated that other key ingredients to passive stability are a competent sealed capsule of appropriate volume, minimal joint fluid, and an intact congruent glenoid labrum (hence, normally attached ligaments) [18]. Furthermore, the capsular ligaments must be balanced to provide passive stability during the dynamics of shoulder motion. Different structures among the static stabilizers cooperate to maintain stability. To exemplify this concept, inferior shoulder instability can develop from either rotator interval lesions (which involves the SGHL and CHL) or from superior labral instability, which are different pathologic processes. Also, deficiencies in one structure could result in higher stresses to other structures within the glenohumeral joint, increasing instability and propagating dysfunction. Indeed, Pagnani et al. have shown that creation of superior labral instability causes increased tension in the inferior glenohumeral ligament complex [24].

6.2. Basis of dynamic stability

Active stability is primarily the result of neuromuscular control between the scapulothoracic musculature and the rotator cuff muscles. The shoulder joint is ideally oriented by the functional scapulothoracic musculature to reduce instability and the neural feedback between the rotator cuff muscles and the glenohumeral ligaments help prevent pathologic translation of the glenohumeral joint. Rapid neural feedback in response to forces that could induce risk of ligament failure probably cause an appropriately protective reaction in most shoulders. Lephart et al. have demonstrated a loss of proprioceptive competence in unstable shoulders [25,13].

Dynamic stabilizers may contribute to joint stability by passive muscle tension from the bulk effect of the muscle, contraction causing compression of the articular surfaces, joint motion that secondarily tightens the passive ligamentous constraints, barrier effect of the contracted muscle, and redirection of the force to the center of the glenoid surface by coordination of muscle forces [21].

Contraction of the rotator cuff muscles results in concavity compression, and asymmetric contraction acts to cause humeral head rotation during shoulder motion. Force couples occur when the resultant force of two opposing muscle groups achieves a given moment. The rotator cuff acts as a force couple around the joint, with coactivation of agonist and antagonist muscles, as well as coordinated activation of the agonist and inhibition of the antagonist muscle. This helps in producing the torques and accelerations necessary for using the glenohumeral joint. The specialized anatomy of the rotator cuff muscles and the long head of the biceps are situated in an ideal configuration to actively compress the humeral head into the glenoid cavity [21]. The rotator cuff muscles lie much closer to the center of rotation on which they act, so their lever arm is shorter and a smaller generated force results. Because of this anatomic location, the rotator cuff is very well situated to provide stability to a dynamic fulcrum during glenohumeral joint abduction. The interaction of the rotator cuff muscles works in conjunction with other muscles in the shoulder girdle. Inman described the cephalad force of the deltoid counteracted by the depressing force of the subscapularis, infraspinatus, and teres minor [11]. In addition, Lee and An quantified the contribution of the deltoid muscle to GH stability during ROM. At 60° on the scapular plane, deltoid activity increased GH joint stability. However at 60° in the coronal plane, deltoid muscle decreased stability [26].

Different components of the rotator cuff contribute to stability throughout abduction. As an example, the infraspinatus and teres minor control external rotation of the humerus and reduce anteroinferior capsuloligamentous strain. An EMG study showed that the subscapularis and the infraspinatus contract to stabilize the glenohumeral joint in abduction at 60–150°. Among the dynamic stabilizers, the biceps has been found to be the most important stabilizer in neutral rotation, with the subscapularis providing the greatest degree of stabilization in external rotation [21].

Disruption of the coupled activity of the rotator cuff muscles can affect the force couples generated and hence contribute to instability. Rupture of the rotator cuff can permit anterior dislocation of the humeral head on an intact anterior soft tissue surface. Furthermore, displacement of the humeral head increases with rotator cuff tear size. Tear size has greatest effect on stability in the inferior direction for tears centered at the critical area (supraspinatus with extension to infraspinatus) and in the anterior direction for tear centered at the rotator interval [21]. Partial tears of the rotator cuff do not generally contribute to instability and can be treated conservatively, unless they comprise more than 50% of the width of the tendon (see Fig. 10). Table 1 includes the rotator cuff tendon insertions as studied by Dugas and colleagues [27]. Based on the medial-to-lateral width of the suprspinatus tendon with an average measurement of 14.7 mm, disruption of more than 7 mm would warrant surgical repair. In addition to size, the particular muscles affected by a rotator cuff tear become important in stability. The stabilizing mechanism of the rotator cuff depends on the integrity of the transverse force couple which is formed by the

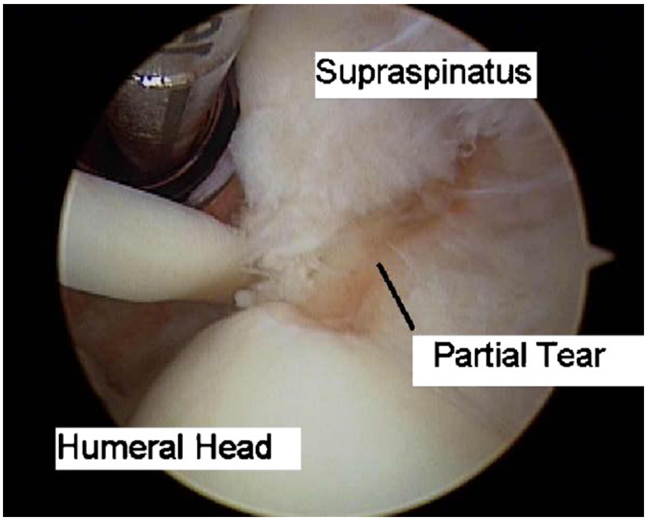

Fig. 10. Partial rotator cuff tear. The rotator cuff inserts very closely to the articular surface of the humeral head (within 1 mm) along the anterior 2.1 cm of the greater tuberosity.

subscapularis anteriorly and by the infraspinatus/teres minor posteriorly. Different rotator cuff tear configurations can affect stability and it was shown that tears involving the infraspinatus/teres minor and subscapularis disrupt the transverse force couple whereas isolated supraspinatus tears could be compensated for by the remainder of the rotator cuff muscles, hence not contributing to instability or superior translation [28].

An extreme example of failure of the coordinated activity of the static and dynamic stabilizers occurs in the setting of massive rotator cuff tears in conjunction with disruption of the coracohumeral ligament and anterior acromion deficiency. As the rotator cuff fails to counteract the cephalad forces of the deltoid, disruption of normal anatomic restraints produces severe anterosuperior translation of the humeral head termed anterosuperior escape.

6.3. *Interation of static and dynamic stabilizers*

The glenohumeral ligaments are usually lax during midranges of motion when the humeral head is centered within the glenoid. As the shoulder approaches end-ranges of motion, the ligaments become progressively tighter, acting as check reins at the ends of the motion arc. Dynamic stabilizers and the configuration of the articular surfaces, labrum, and intraarticular pressure play a role in stabilization in the midrange of motion [21]. Although the dynamic stabilizers are important for midrange of motion stability, their importance in maintaining stability in the end-range of motion has been described. As the glenohumeral joint is taken to end-range positions, the scapulohumeral and rotator cuff muscle interactions work in unison to preserve stability and complement the glenohumeral ligament check reins. Labriola et al. showed that in end-range positions, simulated increases in rotator cuff muscle forces tended to improve the stability while increases in deltoid or pectoralis major muscle forces tended to further decrease stability [29]. With the glenohumeral joint in end-range positions, Itoi et al. found that the subscapularis was a less effective stabilizer of the glenohumeral joint than the other rotator cuff muscles and that the long head of the biceps may contribute to stability [30]. The subscapularis contributes to stability in combination with the middle glenohumeral ligament at mid-ranges of abduction. Turkel et al. showed that at 0° abduction the subscapularis stabilizes the joint to a large extent, and at 45° the subscapularis, MGHL, and anterior-superior fibers of the IGHL provide primary stability, and approaching 90°, the IGHL prevents dislocation during external rotation [31,21]. These studies help demonstrate the coordinated effect of the dynamic and static stabilizers during shoulder range of motion [29].

Excessive forces or repetitive stresses can overpower these stabilizing interactions to produce pathologic conditions. A force that increases the range of external rotation, extension, and abduction may produce failure of IGHL known as a Bankart lesion, with its resulting avulsion of the glenoid labral attachments of the ligament complex. Repetitive stresses can also contribute to gradual failure of the check rein action of the glenohumeral ligaments. When these forces are applied at the end-ranges of motion, such as in pitching, they can produce lesions similar to those caused by traumatic stresses. Bankart lesions have been documented in persons who have shoulder injury from repetitive stresses and have never sustained a shoulder dislocation. However, a more likely finding in such a person would be that of increased ligament length and, subsequently, capsular volume. This increased volume is presumably the result of repetitive interstitial ligament injury with stretching and remodeling [13].

With the increase in intracapsular volume the shoulder can show signs of instability in its mid-ranges. At this clinical point, patients may exhibit signs and symptoms consistent with multidirectional instability (MDI). Signs of gross instability in normally stable shoulder positions can develop, including dislocation during sleep positions. Patients with chronic laxity and multiple subluxations may present with similar symptoms, and its up to the clinician to distinguish between these groups of patients. Surgical stabilization is normally recommended for the former group, whereas the latter group can usually be treated conservatively [13].

7. Conclusions

The glenohumeral joint is a complex articulation with a lack of inherent stability. This is compensated by the intricate interaction between a series of static and dynamic stabilizers. With the use of biomechanical feedback to maintain tension at different ranges of motion, the structures are able to counteract the forces that could potentially destabilize the shoulder joint. Disruption of any of these stabilizing structures can cause clinical manifestations of pain or instability of the shoulder. Furthermore, different injuries and pathologic processes can potentially cause similar clinical presentations. For these reasons it is very important to understand the etiology of these different causative factors so that we can offer effective treatment for patients suffering from shoulder instability.

References

[1] Howell SM, Galinat BJ. The glenoid labral socket. A constrained articular surface. Clin Orthop 1989;243:122–5.

[2] Morrey BF. Shoulder biomechanics. In: Rockwood CA, Matsen III FA, editors. The shoulder. Philadelphia: WB Saunders; 1990. p. 208–45.

[3] Saha AK. Theory of shoulder mechanism: descriptive and applied. Springfield, IL: Charles C. Thomas Publisher; 1961.

[4] Halder AM, Itoi E, An K. Anatomy and biomechanics of the shoulder. Orthop Clin NA 2000;31(2).

[5] Warner JJP, Bowen MK, Deng X, Hannafin JA, Arnoczky SP, Warren RF. Articular contact patterns of the normal glenohumeral joint. J Shoulder Elbow Surg 1998;7:381–8.

[6] DE Wilde LF, Berghs BM, AUdenaert E, Sys G, Van Maele GO, Barbaix E. About the variability of the shape of the glenoid cavity. Surg Radiol Anat 2004; 26:54–59.

[7] Bahk M, Keyurapan E, Tasaki A, Sauers EL, McFarland EG. Laxity testing of the shoulder: a review. Am J Sports Med 2007;35(1): 131–44.

[8] Itoi E, Lee SB, Berglund LJ, Berge LL, An KN. The effect of a glenoid defect on anteroinferior instability of the shoulder after Bankart repair: a cadaver study. J Bone Joint Surg Am 2000;82A:35–46.

[9] Burkhart SS, DeBeer JF, Tehrany AM, Parten PM. Quantifying glenoid bone loss arthroscopically in shoulder instability. Arthroscopy 2002;18:488–91.

[10] Terry GC, Chopp TM. Functional anatomy of the shoulder. J Athlet Train 2000;35(3):248–55.

[11] Inman VT, Saunders JBDCM, Abbott LC. Observations on the function of the shoulder joint. J Bone Joint Surg 1944;26:1–30.

[12] Glousman R, Jobe F, Tibone J, et al. Dynamic electromyographic analysis of the throwing shoulder with glenohumeral instability. J Bone Joint Surg 1988;70A:220–6.

[13] Adkinson DP. Shoulder Biomechanics. In: Steinbach LS, Petrfy CG, Tirman PFJ, Feller JF, Gardner GM, editors. Shoulder magnetic resonance imaging. Philadelphia: Lippincott-Raven Publishers; 1998.

[14] Harryman 2nd DT, Sidles JA, Harris SL, et al. The ole of the rotator interval capsule in passive motion and stability of the shoulder. J Bone Joint Surg Am 1992;74:53–66.

[15] Provencher MT, Mologne TS, Hongo M, Zhao K, Tasto JP, An K. Arthroscopic versus open rotator interval closure: biomechanical evaluation of stability and motion. Arthrosc: J Arthrosc Relat Surg 2007;23(6):583–92.

[16] Burkart AC, Debski RE. Anatomy and function of the glenohumeral ligaments in anterior shoulder instability. Clin Orthop Relat Res 2002;400:32–9.

[17] Wolf EM, Cheng JC, Dickson K. Humeral avulsion of glenohumeral ligaments as a cause of anterior shoulder instability. Arthroscopy 1995;11:600–7.

[18] Sidles JA. American Academy of Orthopaedic Surgeons Shoulder Course, Waikoloa, HI, March 1993.

[19] Karduna AR, Williams GR, Williams JL, Ianotti JP. Kinematics of the glenohumeral joint: Influence of muscle forces, ligamentous constraints and articular geometry. J Orthop Res 1996;14:986–93.

[20] Halder AM, Kuhl SG, Zobitz ME, Larson D, An KN. Effects of the glenoid labrum and glenohumeral abduction on stability of the shoulder joint through concavity-compression: an in vitro study. J Bone Joint Surg 2001;83-A(7):1062–9.

[21] Abboud JA, Soslowsky LJ. Interplay of the static and dynamic restraints in glenohumeral instability. Clin Orthop Relat Res 2002;400:48–57.

[22] Pagnani MJ, Deng X-H, Warren RF, Torzilli PA, O'Brien SJ. Role of long head of biceps brachii in glenohumeral instability: a biomechanical study in cadavers. J Shoulder Elbow Surg 1996;5:255–62.

[23] Rodosky MW, Harner CD, Fu FH. The role of the long head of the biceps muscle and superior glenoid labrum in anterior stability of the shoulder. Am J Sports Med 1994;22:121–30.

[24] Pagnani MJ, Deng XH, Warren RF, et al. Effect of lesions of the superior portion of the glenoid labrum on glenohumeral translation. J Bone Joint Surg Am 1995;77:1003–10.

[25] Lephart SM, Borsa P, Fu FH, Warner JJP. Proprioception of the shoulder joint in normal, unstable and post-capsulolabral reconstructed individuals. In: Presented at the Tenth annual meeting of the American Academy of Shoulder and Elbow Surgeons. 1994.

[26] Lee SB, An KN. Dynamic glenohumeral stability provided by three heads of the deltoid muscle. Clin Orthop 2002:400–7.

[27] Dugas JR, Campbell DA, Warren RF, Robie BH, Millett PJ. Anatomy and dimension of rotator cuff insertions. J Shoulder Elbow Surg 2002;11:498–503.

[28] Parsons IV IM, Apreleva M, Fu FH, Woo SL-Y. The effect of rotator cuff tears on reaction forces at the glenohumeral joint. J Orthop Res 2002;20:439–46.

[29] Labriola JE, Lee TQ, Debski RE, McMahon PJ. Stability and instability of the glenohumeral joint: The role of shoulder muscles. J Shoulder Elbow Surg 2005;14:32S–8S.

[30] Itoi E, Newman SR, Kuechle DK, Morrey BF, An KN. Dynamic anterior stabilisers of the shoulder with the arm in abduction. J Bone Joint Surg Br 1994;76:834–6.

[31] Turkel SJ, Panio MW, Marshall JL, Girgis FG. Stabilizing mechanisms preventing anterior dislocation of the glenohumeral joint. J Bone Joint Surg 1981;63A:1208–17.