Biomechanics and Pathoanatomy of Posterior Shoulder Instability

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KEYWORDS

- Posterior shoulder instability • Glenohumeral instability • Biomechanics
- Posterior subluxation • Posterior dislocation

KEY POINTS

- Posterior glenohumeral instability encompasses a spectrum of pathology related to various anatomic features, including capsuloligamentous anatomy and bony constraints.
- The posterior capsulolabral complex, including the posterior band of the inferior glenohumeral ligament, as well as the posterior labrum, are both essential static soft tissue elements providing posterior glenohumeral stability, and are a common therapeutic target.
- Critical posterior glenoid bone loss, severe retroversion, and engaging humeral lesions must be addressed to adequately restore shoulder stability.
- Emerging concepts such as posterior acromial morphology may play an additional pathoanatomic role in posterior shoulder instability, but further research is needed to characterize its relevance.

INTRODUCTION

Posterior glenohumeral instability is an underrecognized shoulder pathology that accounts for approximately 2% to 10% of all glenohumeral instability cases.[1,2] Estimates of posterior instability incidence have ranged from 4.64 to 23.9 per 100,000 person-years in the general population[2,3] to upwards of 184 per 100,000 person-years in young, active populations such as military personnel and participants in over-head or contact sports.[2,4–6] Recurrent posterior instability is commonly the result of repetitive microtrauma but can also develop following a posterior shoulder dislocation or in the context of hyperlaxity.[7] Posterior shoulder instability represents a diagnostic challenge and is missed in up to 79% of patients.[8–10] Unlike anterior instability, patients with posterior shoulder instability often present with a primary complaint of pain and

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may not necessarily report any perceived instability or recall an identifiable mechanism of injury.[11,12]

While many initially considered posterior shoulder instability to simply be the counterpart of anterior instability, surgeons now recognize posterior shoulder instability as a distinct clinical and pathoanatomic entity. Posterior shoulder stability depends upon a complex interplay between soft tissue and osseous restraints that are distinct from anterior instability. For example, the glenoid version has been shown to play a substantial role in posterior shoulder instability, and can be targeted as a therapeutic modality to enhance shoulder stability.[13,14] In recent years, there has been improved awareness and understanding of posterior instability, with a concomitant growing body of biomechanical and clinical work in this field. Therefore, in the current article, we seek to review the pathoanatomy and biomechanics of posterior shoulder instability. This review will focus on evaluating the morphologic features, such as glenoid and humeral bone loss and capsuloligamentous pathology, in addition to reviewing the biomechanical literature which defines our current understanding of the pathoanatomy of posterior shoulder instability.

DISCUSSION

Pathoanatomy

Capsuloligamentous anatomy

There are several key soft tissue and bony constraints to the glenohumeral joint that confer stability, and, when injured, deficient, or otherwise incompetent, can lead to posterior shoulder instability. Beginning with capsuloligamentous anatomy, the role of the inferior glenohumeral ligament complex (IGHLC) has long been and remains an active area of investigation.[15–19] Grossly, the posterior capsule is thinner, yet more capacious than its anterior counterpart.[18] Histologically, the IGHLC is comprised of anterior and posterior bands of collagen representing the anterior IGHL and posterior IGHL (PIGHL), respectively, which are joined by a thickened area of the inferior capsule termed the axillary pouch.[18] Of specific relevance to this topic is the PIGHL, which originates from the glenoid surface and/or adjacent bone and labrum ranging from the 7 to 9 o'clock position on the glenoid face.[18,20] The entirety of the IGHLC inserts along the proximal humerus in either a "collar-like" or "v-shaped" fashion, with the PIGHL attaching directly adjacent to the articular margin of the humeral head in either scenario.[18] Due to its material properties and anatomic orientation, the PIGHL is critical to posterior shoulder stability when the glenohumeral joint is abducted 90° and forward flexed 30° (with respect to the plane of the scapula).[19,21] When incompetent, this structure can be a cause of recurrent posterior instability (**Fig. 1**).

Glenoid labrum

The glenoid labrum is well known to be a robust static stabilizer to the glenohumeral joint and affords deeper concavity and conformity to the glenohumeral articulation, increases the suction cup effect of the joint, and serves as a soft tissue boundary to humeral head translation.[22–24] Although substantial variation exists among individuals in labral width and thickness, the posterior labrum is typically larger than the anterior labrum.[25,26] In cross-section, the shape of the posterior labrum may also differ from the anterior labrum. Most commonly, the labrum has a triangular shape in roughly 50% of individuals; however, this shape may be rounded in up to 33% of posterior labrums, compared with only 17% in anterior labrums.[27] Additionally, the posterior capsular tissue inserting onto the labrum is not as robust as its anterior counterpart, with the posterior band of the IGHL thinner than the anterior band in 75% of individuals.[25] Disruption to the posterior labrum can lead to increased propensity for

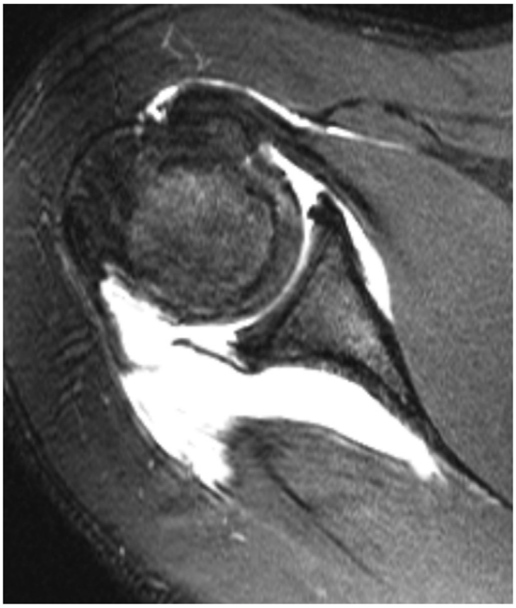

Fig. 1. An axial magnetic resonance arthrogram image of a patient with recurrent posterior instability and an avulsion of the posterior band of the inferior glenohumeral ligament from the humeral head.

posterior shoulder subluxation or dislocation (Fig. 2A and B). When this is the case, arthroscopic surgical repair of the posterior capusulolabral tissue with or without augmentation is the recommended management of this injury as it provides improved glenohumeral biomechanics, enhances posterior stability, and contributes to excellent patient-reported outcomes.[28–33]

Glenoid bony anatomy

As mentioned, the congruence of the glenohumeral articulation is an essential component of shoulder stability. However, multiple posterior shoulder instability events can

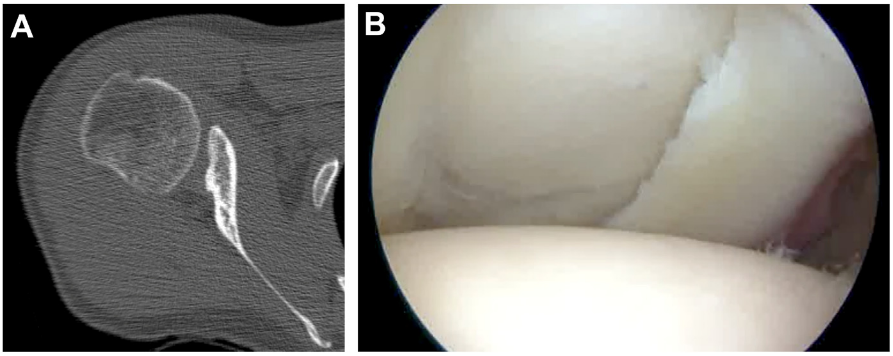

Fig. 2. (*A*) A computed tomography axial slice of a patient with severe glenoid dysplasia and posterior shoulder instability. (*B*) An arthroscopic view of the same shoulder, demonstrating a hypertrophic and torn posterior labrum, as viewed from a high posterolateral viewing portal. Note the hypertrophic labral tear on the right side of the image.

lead to posterior glenoid bone loss and subsequent glenoid retroversion, both of which further potentiate the problem. Although originally designed to assess anterior glenoid lesions, one accepted technique in quantifying posterior glenoid bone loss is the best-fit circle method.[34] This approach uses the area of missing bone within a circle best-fit to the radius of curvature of the inferior aspect of the glenoid face to quantify the amount of glenoid bone loss. While this has been a widely applied technique, the contralateral comparison method compares the width of the affected glenoid to the unaffected contralateral glenoid to determine the percentage of bone loss, though bone deficiency can be bilateral in dysplasia cases. Recent work by Kuberakani and colleagues[35] demonstrated superior intra- and interobserver reliability with the contralateral comparison technique versus the best-fit circle method (0.98 vs 0.91 and 0.88 and 0.77, respectively). The percentage of posterior glenoid bone that must be deficient to be considered critical posterior glenoid bone loss remains of active area of investigation. One recent case-control study of 75 patients demonstrated a 10 times higher failure rate of arthroscopic posterior capsulolabral repair in the setting of 11% posterior glenoid bone loss and 25 times higher with 15% bone loss suggesting a point at which soft tissue repair alone may not be sufficient for managing this subset of patients.[36]

Glenoid retroversion

Closely related to posterior glenoid bone loss, and one of the most important pathoanatomic differences between anterior and posterior shoulder instability, is glenoid retroversion.[14,37] Normally, the glenoid is positioned in between 5 and 6° of retroversion.[38] However, it is conceivable and has been demonstrated clinically that those with increased retroversion experience posterior shoulder instability more frequently than those with normal retroversion contributing to preferential posterior wear of the glenoid and eventual glenoid bone loss.[13] Owens and colleagues[39] demonstrated that pathologic glenoid retroversion is closely connected with glenoid bone loss, as glenoid retroversion greater than 10° is associated with increased posterior glenoid bone loss. This recurrent process in conjunction with the deterioration of the posterior soft tissue constraints can make treating patients with recurrent posterior shoulder instability in the setting of increased retroversion and critical bone loss considerably difficult, and may require glenoid vault reconstruction with or without a scapular neck osteotomy.

Humeral head

Humeral sided lesions (ie, reverse Hill-Sachs lesions (RHSL)) must also be considered when addressing posterior shoulder instability. More commonly occurring following frank dislocations rather than more subtle presentations of posterior shoulder instability, RHSLs can vary in size, position, and clinical significance.[40,41] Computed tomography (CT) or magnetic resonance imaging (MRI) should be obtained to evaluate for the specific anatomic nature of a humeral sided bony lesion.[42] Lesions are commonly classified via their size relative to the articular surface: lesions are considered small when the RHSL involves 0% to 20% to 25%, medium between 20% to 25%, and 45% to 50% and greater as large. Moroder and colleagues reported a technique to measure RSHLs, with specific attention to assessing for lesions that would be likely to engage in the posterior glenoid, similar to the on-track, off-track concept of anterior shoulder instability.[43–45] These authors introduced the measurement of an angle which may be prone to re-engagement (ie, the gamma angle). This angle is measured from the bicipital groove to the most posterior aspect of the RHSL, with a measurement of greater than 90° thought to be susceptible to re-engagement (Fig. 3).[46] They performed a subsequent analysis evaluating bipolar bony lesions in posterior shoulder instability, finding that, similar to its anterior counterpart, glenoid bone loss can make even noncritical size lesions engage and thus prone to redislocation.[44]

Acromion

Historically, surgeons have considered the osseus restraint of the posterior glenoid on the humeral head as the primary bony constraint of the glenoid. In recent years however, the acromion has become increasingly implicated as a risk factor for shoulder instability.[47–52] The first mentions of any potential connection between the acromion and posterior instability was in the form of posterior acromial augmentation to treat unidirectional posterior shoulder instability.[52] Per his report, Scapinelli and his colleagues demonstrated good results with performing a scapular spine autograft to the posterolateral acromion to provide a mechanical buttress to the humeral head in the management of posterior instability.[52] While his work did not directly suggest the acromion to be a pathoanatomic structure in these patients, he indirectly proposed the importance of acromial morphology in posterior instability by using the acromion as a therapeutic target.

Subsequently, Meyer and colleagues[51] found that a tall and flat acromion was highly associated with posterior instability when compared with anterior instability or a group of control patients. These authors posed the concept that a lower, more tilted acromion may serve a mechanical advantage when it comes to posterior instability by providing a buttress to the humeral head and thus decreasing its propensity for instability episodes. Another group sought to examine the relationship between acromial morphology and posterior glenoid bone loss in posterior instability patients.[50] These researchers determined that the same risk factors identified by Meyer and colleagues for posterior instability—a high, flat acromion—were also associated with increased posterior glenoid bone loss. Again, this expands the literature suggesting the potential pathoanatomic connection between posterior acromial morphology and posterior shoulder instability.[50]

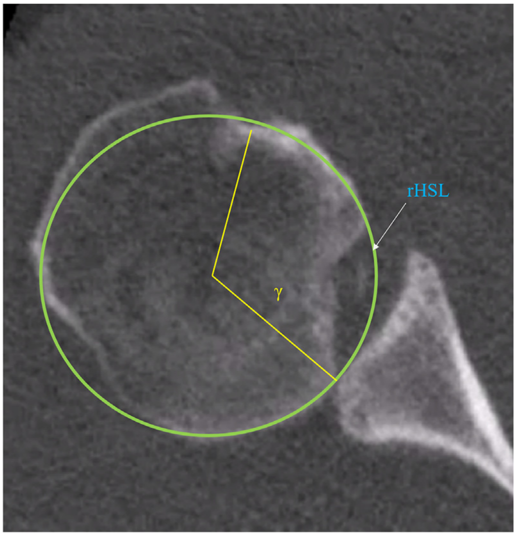

Fig. 3. An axial CT slice of a large reverse Hill-Sachs lesion, with a gamma angle of greater than 90°.

Biomechanics

The complex balance between active and passively stabilizing soft tissue and osseous restraints affords the shoulder the greatest range of motion of all joints in the human body.[53,54] Unfortunately, this wide range of motion also comes at the price of the greatest risk of instability. Initially thought to be the biomechanical converse to anterior shoulder instability, researchers have assessed the biomechanics of posterior instability and characterize this unique phenomenon as a distinct pathoanatomical process. In the following section, we will review the relevant literature and highlight the biomechanical features of the structures associated with posterior shoulder stability.

Position of instability

Posterior shoulder dislocations are well-described to occur in the setting of three primary, concurrent humeral positions: flexion to 90°, internal rotation, and adduction.[55–58] Patients who present with posterior shoulder instability as the result of microtrauma and subluxation episodes often experience symptoms during activities such as bench press, pushups, or blocking in football as the forces imparted on the shoulder in this position reproduces pain from posteroinferior labral tears.[14] However, several biomechanical studies have also tested posterior shoulder stability using less forward humeral flexion and varying degrees of humeral abduction with the shoulder in neutral rotation, simulating the posterior load-and-shift testing position.[21,59,60] For example, 30° of humeral flexion with an abducted shoulder is the position in which the posterior band of the inferior glenohumeral ligament becomes the primary antero-posterior stabilizer of the glenohumeral joint, describing an important pathoanatomic connection to this scapulohumeral position.[21]

Capsulolabral complex biomechanics

The PIGHL and the posterior labrum are essential soft tissue structures implicated in posterior shoulder instability, and are therapeutic targets for repair when nonoperative management of posterior labral tear fails.[61] The anatomic and biomechanical properties of these structures, as well as the pathoanatomic derangements when injured, are of particular importance in this clinical context.

The PIGHL biomechanically differs appreciably from the anterior band of the IGHL. Bigliani and colleagues[16] demonstrated that the tensile properties of the PIGHL are inferior to that of the anterior pouch and superior band, as the posterior band is thinner and exhibits a lower strain to failure. Ticker and colleagues also evaluated the geometric and strain-rate dependent properties of the IGHL, once again finding that the posterior band was thinner, demonstrated inferior tensile stress to failure, and lower bone-to-bone and mid-substance strains than the other regions of the ligament.[62] When combined with a posterior labral lesion, a posterior capsular injury results in a significant increase in the posterior and inferior translation of the humeral head, demonstrating the bidirectional (ie, posterior and inferior) importance of this ligament.[63] This group also found increased humeral head translation when adding a rotator interval injury (superior glenohumeral ligament and coracohumeral ligament), suggesting the importance of the superior capsule in posterior shoulder stability. This is in accordance with a biomechanical study performed by Harryman and colleagues[64] in 1992, which identified significant posteroinferior instability when sectioning the rotator interval and improved resistance to posterior and inferior translation when imbricating the rotator interval. On the contrary, Mologne and colleagues[65] found no increase in resistance to posterior translation when adding an arthroscopic rotator interval closure after posterior capsulolabral repair, but did find a significant decrease in external rotation following this procedure. As a result, controversy remains as to the biomechanical relevance of the rotator interval on posterior shoulder instability.

The posterior labrum acts as both a bumper to posterior humeral head translation, but also an essential component of the suction effect maintaining humeral head concentricity within the glenoid. Many cadaveric biomechanical studies have demonstrated increasing humeral head translation or decreased force to translate the humeral head posteriorly and/or inferiorly in the context of a posterior labral tear when studying posterior shoulder instability.[59,60,63,66] In a cadaveric biomechanical study of posteroinferior labral lesions, Wellman and colleagues[63] found an 86% increase in posterior humeral head translation and a 31% increase in inferior translation when simulating a posterior Bankart lesion. Accordingly, Waltz and colleagues[67] reported that a posterior labral repair significantly decreases the posterior–inferior translation of the humeral head up to 2.3 mm when compared with labral tear states when applying 75 N of posteroinferior force to the humeral head using a cadaveric model. These results demonstrate the biomechanical importance of posterior labral repairs in restoring posterior shoulder stability, but as we will highlight in the upcoming section, labral repair alone may be insufficient to restore posterior stability in the context of severe posterior glenoid bony deficiency.

Glenoid bone loss and retroversion

The glenoid is an essential osseous restraint to both anterior and posterior shoulder instability. As previously described, the glenoid is a concave structure, with a central depression and elevation eccentrically throughout its circular arc. On average, the glenoid is retroverted approximately 5 to 6° relative to the plane of the scapula.[38] Several glenoid abnormalities can predispose to posterior shoulder instability including higher degrees of retroversion, loss of glenoid concavity and tilt, or posterior glenoid bone loss from recurrent instability episodes.[13,60,68]

While the pathoanatomic features and surgical treatments for anterior instability have been well-established over the years, only more recently have surgeons emphasized posterior glenoid bone loss in recurrent posterior instability. Nacca and colleagues[60] performed a cadaveric biomechanical study to evaluate the critical amount of posterior glenoid bone loss at which a posterior labral repair alone would be insufficient to restore shoulder stability. This group found that an osseous defect of greater than 20% of the glenoid width could not be effectively stabilized with a reverse Bankart repair alone. Waltz and colleagues attempted another biomechanical study to evaluate the effectiveness of a reverse Bankart repair in the setting of posterior glenoid bone loss, finding that smaller-sized osseous defects could be stabilized with a reverse Bankart repair alone. However, in their larger defect group (>25% of the glenoid width), labral repair alone could not restore stability to the native state.[67]

The biomechanical effect of glenoid retroversion has also been studied regarding both glenohumeral osteoarthritis and posterior shoulder stability. In a study aimed to evaluate the amount of posterior glenoid wear before posterior humeral head subluxation occurred (ie, in the case of a Walch B2 glenoid), Bryce and colleagues[69] found that posterior humeral head translation increased with even 5° of posterior glenoid bone loss (equating to 2.5° of glenoid retroversion) depending on the position of the humerus. When considering posterior shoulder instability, Levins and colleagues[59] found in their cadaveric biomechanical study that each degree of retroversion accounted for a 3.5% decrease in resistance to posterior humeral head translation. Their results also suggested that repairing the posterior labrum does not restore posterior shoulder stability when retroversion exceeds 20 to 25°, implying that bony anatomy may be more relevant at higher degrees of glenoid retroversion. Ernstbrunner and colleagues[70] performed a biomechanical analysis of a posterior glenoid opening-wedge osteotomy using a J-shaped iliac crest graft, finding that reconstructing the glenoid to 0° of retroversion significantly improved shoulder stability in the setting of either a posterior labral lesion or posterior glenoid bone loss (**Fig. 4**). Similarly, Marcaccio and colleagues[66] found a posterior glenoid opening wedge osteotomy to be a useful biomechanical option in the treatment of posterior glenoid bone loss. However, while a posterior glenoid osteotomy appears to be biomechanically beneficial, the clinical results are suboptimal; at long-term follow-up, these patients have unfortunately high rates of glenohumeral arthritis.[71]

Humeral head

The biomechanical data assessing humeral head lesions in posterior shoulder instability are limited.[44,46] To the best of our knowledge, there are no cadaveric biomechanical studies performed in this realm. Moroder and colleagues has however performed the previously mentioned analysis to assess for engagement in bipolar bone defects.

This group used 19 cases of posterior shoulder dislocations with no posterior glenoid bony defects. They performed various measurements using CT scans, created virtual posterior glenoid defects, all with the goal of identifying the size and location of RHSL and amount of posterior glenoid bone loss that could lead to re-engagement. The authors found that each millimeter of posterior glenoid bone loss decreased the range of achievable humeral internal rotation prior to the re-engagement of the RHSL by 2.3° (also known as the delta angle).[44]

Acromion

There is limited biomechanical data assessing the role of acromial morphology in posterior shoulder instability. Testa and colleagues[72] performed a cadaveric biomechanical study evaluating the utility of a posterior acromial bone block in the treatment posterior shoulder instability. Their results found that posterior acromial augmentation

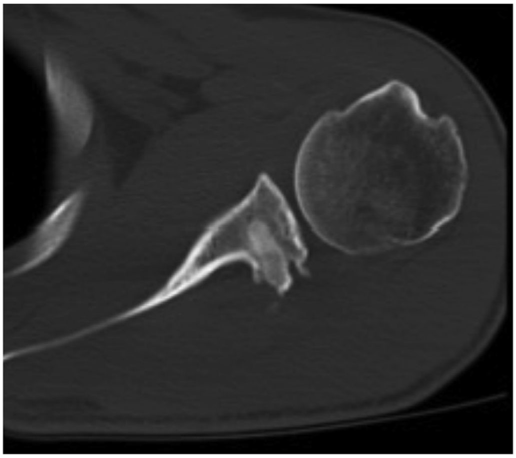

Fig. 4. A CT image in the axial plane of a shoulder after a posterior glenoid opening wedge osteotomy was performed. (Image courtesy of Elselvier Open Access publication; and Citation: Waltenspül, M, Häller, T, Ernstbrunner, L, Wyss, S, Wieser, K, Gerber, C: Long-term results after posterior open glenoid wedge osteotomy for posterior shoulder instability associated with excessive glenoid retroversion. J Shoulder Elbow Surg 2022;31:81–89.[68])

with a scapular spine bone block is biomechanically effective at restoring the force required to translate the humeral head posteriorly, and produces superior resistance force to humeral head translation than a posterior capsulolabral repair alone. Future biomechanical research in this area will be interesting to characterize any biomechanical relationship between posterior acromial morphology and posterior shoulder instability.

SUMMARY

Posterior glenohumeral instability encompasses a spectrum of pathology related to various anatomic features, including capsuloligamentous anatomy and bony constraints. While much attention is paid to the posterior capsulolabral complex, the osseous anatomy is of great importance when considering the biomechanical stability of the shoulder. Critical posterior glenoid bone loss, severe retroversion, and engaging humeral lesions must be addressed to adequately restore shoulder stability. Emerging concepts such as posterior acromial morphology may play an additional pathoanatomic role in posterior shoulder instability, but further research is needed to characterize its relevance.

CLINICS CARE POINTS

- Posterior glenohumeral instability encompasses a spectrum of pathology related to various anatomic features, including capsuloligamentous anatomy and bony constraints.
- The posterior capsulolabral complex, including the posterior band of the inferior glenohumeral ligament, as well as the posterior labrum, are both essential static soft tissue elements providing posterior glenohumeral stability, and are a common therapeutic target
- Critical posterior glenoid bone loss, severe retroversion, and engaging humeral lesions must be addressed to adequately restore shoulder stability.
- Emerging concepts such as posterior acromial morphology may play an additional pathoanatomic role in posterior shoulder instability, but further research is needed to characterize its relevance.

DISCLOSURE

No relevant disclosures.

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