Internal Impingement: A Review on a Common Cause of Shoulder Pain in Throwers

Steven Behrens, MD; Jeffrey Compas, BA; Matthew E. Deren, BS; Mark Drakos, MD

Abstract: Internal impingement refers to a condition classically occurring in younger, active overhead athletes. This has been postulated to occur due to the many. The repetitive nature of the overhead athlete's activities under extreme loading conditions at the limits of functional shoulder motion result in tremendous strain. Over time, this results in both soft tissue and osseous adaptations to the normal morphology of the glenohumeral joint. Internal impingement occurs when these morphological changes lead to abnormal contact between the undersurface of the rotator cuff tendons and the posterior margin of the glenoid, resulting in a painful shoulder.

Keywords: internal impingement; shoulder; throwers

Steven Behrens, MD[1]
Jeffrey Compas, BA[2]
Matthew E. Deren, BS[1]
Mark Drakos, MD[1]

[1]Department of Orthopedics Brown University, Warren Alpert School of Medicine, Providence, RI;
[2]New York College of Osteopathic Medicine, Westbury, NY

Introduction

Internal impingement refers to a condition classically occurring in younger, active overhead athletes. This has been postulated to occur due to the many. The repetitive nature of the overhead athlete's activities under extreme loading conditions at the limits of functional shoulder motion result in tremendous strain. Over time, this results in both soft tissue and osseous adaptations to the normal morphology of the glenohumeral joint. Internal impingement occurs when these morphological changes lead to abnormal contact between the undersurface of the rotator cuff tendons and the posterior margin of the glenoid, resulting in a painful shoulder.[1,2] This pathologic contact is distinct from asymptomatic contact between the posterior glenoid and the rotator cuff,[3,4] and may result in injury to the labrum or rotator cuff. Thus, this entity is defined by the pathologic biomechanics of repetitive throwing rather than the constellation of various pathologies (rotator cuff tears, labral tears, anterior laxity) that the patient may present with. This injury is distinct from the subacromial impingement originally described by Neer et al.[5,6] In addition, Jobe et al[2,7] described instability-associated impingement in athletes, and other authors have improved our understanding of the etiology of pain in the overhead athlete. This article reviews the literature and current understanding of internal impingement, including the limitations of available evidence and treatment strategies.

Historical Perspective

In 1959, Bennett[8] first described posterior shoulder pain in the throwing arms of professional baseball players, attributing the symptoms to inflammation of the posterior shoulder capsule and the insertion point of the triceps tendon. The pain was associated with a radiographic finding called the Bennett lesion, which refers to exostosis at the posteroinferior glenoid rim. In 1977, Lombardo et al[9] further described an open approach to the treatment of posterior shoulder pain in throwers, finding both ossification of the posterior capsule and increased fibrosis of the surrounding tissues in the affected shoulder. This provided visual evidence of the Bennett lesion, but did not offer further insight into possible treatment options for the pain.

In 1985, Andrews et al[10] reported on the debridement of partial supraspinatous tears in overhead athletes that were discovered on arthroscopic examination. On follow-up, 85% of the patients returned to premorbid athletic condition. The authors concluded that the debridement process aided in the healing of the partial rotator cuff, but they did not offer a mechanism of injury. Instead, Andrews et al[10] observed that the pain occurred primarily during throwing, and suggested that the repeated stresses placed on the shoulder during the throwing motion caused the injury.

Correspondence:
Mark Drakos, MD,
Department of Orthopedics,
Brown University,
warren Alpert School of Medicine,
100 Butler Dr.,
providence, RI 02906.
E-mail: mdrakos@yahoo.com

Posterior shoulder pain was first associated with posterosuperior glenoid impingement and anterior instability of the shoulder in 1989.[11] Anterior capsulolabral reconstruction with appropriate rehabilitation was performed in 25 patients presenting with this constellation of symptoms, with excellent results reported in 68% of patients, and good results reported in 24%.[12] In this subset of patients, Jobe et al[12] noted the failure of subacromial decompression in throwers with symptoms of impingement, further distinguishing this condition from that of classical subacromial impingement. The authors offered a mechanism for these pathologies, believing that anterior instability of the shoulder led to capsular stretch resulting in the symptoms of impingement. The authors also noted injuries to the superior and inferior labrum, rotator cuff tendons, greater tuberosity, inferior glenohumeral ligament, and superior glenoid bone.

In 1991, Walch et al[13] reported single case of a young thrower who developed a partial tear on the deep surface of the supraspinatous tendon against the posterosuperior glenoid.[13] With the arm abducted and externally rotated, the patient developed pain, and the partial tear was visualized by arthroscopy. Walch et al[1] then examined 17 patients with undersurface rotator cuff tears treated by arthroscopy, and provided the first clinical evidence to support internal impingement as a cause of shoulder pain.

Biomechanics

The forces applied to the shoulder by the overhead athlete can lead to a variety of pathologic changes in the labrum, biceps, rotator cuff, capsule, and glenoid. Asymptomatic contact between the rotator cuff tendons and the posterosuperior glenoid has been demonstrated in cadaveric studies, thus contact alone may not be enough to cause the disease.[3,4] The mechanics of the different phases of throwing have been studied extensively, and poor throwing technique has been shown to result in shoulder disease.[14,15] Muscle fatigue and imbalance can also affect mechanics, leading to humeral hyperextension in the late-cocking phase of throwing, a condition in which the rotator cuff cannot completely resist the large acceleration forces. This may lead to damage of the posterior capsulolabral structures.[3] During the follow-through phase of throwing, rapid deceleration of the arm can lead to abrasions of the rotator cuff on the posterosuperior glenoid and scapular dysfunction, resulting in symptoms known as "dead arm" syndrome.[16,17] This condition is further permitted by the development of anterior capsular microinstability, although some believe that the anterior laxity found in internal impingement is actually a pseudolaxity, noting a functional lengthening of the anterior capsule.[18] The "peel-back" mechanism also has been proposed, in which the posteroinferior capsular contraction leads to translation of the humeral head. The biceps and labrum may then "peel off" of the glenoid, implicating a hypertwist mechanism because of the large sheer forces.

Pathophysiology

Internal impingement can present as a constellation of pathologic processes, including partial- or full-thickness rotator cuff tears; anterior or posterior capsular injury; labral tears; glenoid chondral erosion; chondromalacia of the posterosuperior humeral head; and biceps lesions. Moreover, the absence of these lesions does not exclude a diagnosis of internal impingement. Rather, the changes that occur as a result of pitching lead to excess stress being placed on several of the stabilizing structures of the glenohumeral joint. These changes can occur in the overhead athlete as a result of shoulder stress from the throwing motion. Repetitive overhead activity at high velocity allows for adaptations in shoulder morphology. In the throwing arms of baseball pitchers, a maximal internal rotation of 7000° per second has been observed, which is the fastest of all overhead athletes.[19] The throwing mechanics have been extensively detailed, and the distraction force acting on the posterior-inferior capsule has been shown to be > 750 N during the follow-through phase.[20]

As a result of these forces acting on the shoulder, adaptation occurs within the joint. In the shoulders of elite overhead athletes, there is increased glenohumeral external rotation, anterior capsular laxity, and increased humeral head and glenoid retroversion.[4,5,12,21–23] In addition, the associated posterior capsular contracture that is often seen in overhead athletes results in a glenohumeral internal rotation deficit (GIRD). Glenohumeral internal rotation deficit has been documented in overhead athletes with superior labral anterior to posterior (SLAP) II tears, as proven by arthoscopy.[18] The association between GIRD and the Bennett lesion is unclear. In one study of professional baseball pitchers, the authors noted a 22% prevalence of Bennett lesions in 55 asymptomatic pitchers, demonstrating that the lesion is a common finding, but failing to define its role in internal impingement of the shoulder. Because of this high rate of asymptomatic Bennett lesions and past failure of treatment options targeting the lesion, patients with posterior shoulder pain and an identified Bennett lesion should be worked up for concomitant pathology.

Other studies have investigated the kinematics of throwing, shoulder rotation, and adaptation of the joint using cadavers. To examine the effects of capsular changes in overhead athletes, Grossman et al[24] used a cadaveric model of posterior capsular contracture, which resulted in a significant decrease in internal rotation. The authors concluded that with these capsular changes, the humeral head translated posterosuperiorly during the cocking phase of throwing, possibly resulting in lesions of the posterosuperior labrum. Huffman et al[25] further studied posterior humeral translation in maximal external rotation, and concluded that the shoulder allowed for greater external rotation and increased anterior capsular laxity in response to posterior capsular contraction. In a small retrospective study of patients with internal impingement, Tirman et al[26] noted anterior instability. However, the question remains whether this finding should be identified as a pathologic or an adaptive process, resulting in instability or subluxation. Furthermore, anterior instability is an important clinical finding and should be addressed in patients with internal impingement because unsatisfactory outcomes have been shown in this group, in whom anterior capsulolabral injuries were not repaired.[27–31]

Injury to the rotator cuff tendon can also present with symptoms of internal impingement. Partial-thickness, articular-sided rotator cuff tears have been described. The likely mechanism of this injury is due to repetitive microtrauma of the rotator cuff, particularly during the deceleration phase of the throwing motion in combination with capsular laxity.[27,28,32–34] Several studies of overhead athletes demonstrate the high rate of concurrence of articular-sided rotator cuff tears, with the symptoms and the presence of such tears as a key finding in the diagnosis of internal impingement.[1,4,33] However, the importance of these deep-surface rotator cuff tears has been refuted, as Connor et al[35] reported that 40% of asymptomatic dominant shoulders in 20 elite overhead athletes demonstrated either partial- or full-thickness tears on magnetic resonance imaging (MRI) compared with no detection of such lesions in the nondominant shoulders. With this knowledge of the prevalence of asymptomatic tears, Yamanaka and Matsumoto[36] examined the natural history of partial rotator cuff tears in 40 older patients by arthrography, reporting that 20% of the tears healed or decreased in size, 52.5% increased in size, and 27.5% progressed to full-thickness tears.[36] Again, the study population had a mean age of 61 years, and to date, we know of no studies characterizing the natural history of partial rotator cuff tears in young, active overhead athletes.

Injuries to the superior labrum are well described in the literature; however, there is no clear evidence on whether the lesion is diagnostic or essential for the occurrence of internal impingement. Walch et al[1] described a 71% incidence of posterosuperior labral lesions in 17 patients with internal impingement. Similarly, Paley et al[4] used arthroscopy to identify posterosuperior labral fraying in 88% of 41 overhead athletes with internal impingement. Kaplan et al[37] conducted a retrospective review of MRI scans of 9 symptomatic patients, and all were found to have posterosuperior labral lesions. In a larger prospective cohort study of 376 patients undergoing arthroscopic shoulder surgery, 74% of those with internal impingement also had type II SLAP lesion, leading the authors to conclude that internal impingement may lead to labral tears. However, in a study of 10 college baseball athletes, Halbrecht[38] identified 3 superior labral tears in the throwing shoulders of the athletes, but this result had no clinical correlation to instability on examination.

Clinical and Radiographic Assessment

The assessment of a patient with possible internal impingement should begin with a detailed history. The patient may describe the onset of posterior shoulder pain, particularly during the late-cocking phase of throwing, when the arm is in 90° of abduction and full external rotation. The pain is common in overhead athletes such as pitchers and tennis players. Jobe[7] developed a classification scheme to further distinguish between the varying severities of internal impingement (Table 1). Muscular asymmetry and differing degrees of laxity are common in the overhead athlete when comparing the dominant and nondominant shoulders. As described previously, internal impingement can lead to increased global laxity and anterior translation of the glenohumeral joint. Myers et al[22] examined the range of motion of the glenohumeral joint in throwers with pathologic internal impingement and found that these athletes had 10° to 15° of internal rotation deficit and increased posterior shoulder tightness compared with controls. This evidence was supported by a study of collegiate baseball players with shoulder pain who had a smaller total arc of motion and an internal rotation deficit in the affected dominant shoulder when compared with both the nondominant and asymptomatic control players' shoulders.[39]

The glenohumeral joint may have subtle instability in internal impingement. However, it can be extremely difficult

Table 1. Jobe Clinical Classification of Internal Impingement

Stage	Symptoms
Stage I: early	Shoulder stiffness and a prolonged warm-up period; discomfort in throwers occurs in the late-cocking and early acceleration phases of throwing; no pain is reported with activities of daily living.
Stage II: intermediate	Pain localized to the posterior shoulder in the late-cocking and early acceleration phases of throwing; pain with activities of daily living and instability are unusual.
Stage III: advanced	Similar to those in stage II who have been refractory to nonoperative treatment modalities.

for even the most experienced physician to distinguish between physiologic asymmetric laxity of the joint and pathological microinstability. This is because virtually all throwers have some laxity. To maximize velocity, the shoulder requires more external rotation in the late-cocking phase of throwing. This allows for greater arc of acceleration during the wind-up. This is accomplished by some of the aforementioned morphologic adaptations, but anterior laxity is virtually a prerequisite. Thus, most high-level pitchers will have some laxity. However, the important factor to distinguish is when this laxity leads to instability or clinical symptoms. Some signs of the pathologic process include a so-called "dead arm," the feeling of shoulder and arm weakness after throwing, and a subjective sense of slipping of the shoulder. These historic events can be further evaluated using the posterior impingement test, in which the patient's shoulder is placed in 90° to 100° of abduction, 110° to 115° of extension, and then moved into maximal external rotation; a positive test reproduces the athlete's pain (Figure 1).[40,41] This test has been found to be even more sensitive when performed on athletes with noncontact injuries.[33]

On physical examination, the Neer test for classical shoulder impingement is usually negative in these athletes with internal impingement. The impingement test of Jobe[7] is performed by facing the patient, placing the arm in 90° to 100° of abduction and maximal external rotation, and applying anterior traction to the arm to reproduce the pain. A positive test is associated with a "kissing lesion" of both the glenoid and the rotator cuff.[2] Often, these athletes have comorbid shoulder conditions, including tendonitis, SLAP tears, cysts, and bursal-sided rotator cuff tears, which render the physical examination more obscure.

The next step in diagnostic evaluation of a patient with posterior shoulder pain is to obtain standard radiographs of the affected arm. These should consist of internal and external anteroposterior, scapular Y, and axillary or West Point views, with particular attention to gross malalignment, although subtle findings are more likely. The Bennett lesion can often be identified on axillary or West Point views.[8,42] Attention should also be paid to the base of the greater tuberosity in the anteroposterior external rotation view because this radiograph can demonstrate sclerosis at the base of the tuberosity.

The next modality useful for diagnosis of internal impingement is MRI. Both sensitivities and specificities of $> 95\%$ have been shown for MRI in detection of rotator cuff and labral tears.[43,44] Magnetic resonance imaging is particularly useful for the diagnosis of intrasubstance tears, which are not easily visualized on arthroscopy. In patients with internal impingement, MRI may show evidence of tears, especially on the articular surface of the rotator cuff and the intersection of the infraspinatus and supraspinatus tendon insertions to the humeral head. The tear is often not full thickness, but a small percentage of the size of the tendon. As tears become smaller, the detection of such lesions becomes more difficult using standard MRI. Injection of gadolinium into the joint can aid in diagnosis and increase the rate of detection to 84% for small tears under 25% of the total rotator cuff diameter.[33]

Figure 1. Posterior impingement sign. This is performed with the patient supine and the affected arm in 90–100° of abduction, maximal external rotation, and 10° of forward flexion.

Risks involved in this procedure include an intra-articular injection, pain, and reaction to the contrast agent; however, noncontrast or high-resolution MRI can be effectively used to diagnose superior labral lesions without these associated risks.[44] In patients with clinically or operatively diagnosed internal impingement, imaging studies have shown undersurface tears of the supraspinatous and infraspinatus tendons as well as cystic changes of the posterior humeral head with evidence of posterosuperior labral pathology.[44]

A patient presenting with posterior shoulder pain due to internal impingement may present with this constellation of findings. In addition, the Bennett lesion may be demonstrable by imaging as mature periosteal bone formation at the scapular attachment of the posterior capsule (Figure 2). Moderate-to-severe posterior capsular contracture may be present at the level of the posterior band of the inferior glenohumeral ligament. Pressure on the posterior glenoid with the arm abducted and externally rotated may lead to remodeling of the glenoid, including subchondral depression and large osteophyte formation. The resulting anatomical changes can narrow the spinoglenoid notch near the suprascapular neurovascular bundle. The clinician must be aware of the prevalence of asymptomatic lesions on MRI. In a study of the throwing shoulders of college baseball pitchers, 4 of 10 pitchers had abnormal signal changes in the rotator cuff, and more importantly, no correlation between imaging and physical examination or symptoms was appreciated.[38] This study is reinforced by others who have demonstrated partial cuff tears in completely asymptomatic patients, thus stressing the need for clinical correlation between imaging, history, and physical examination.[34,35,45]

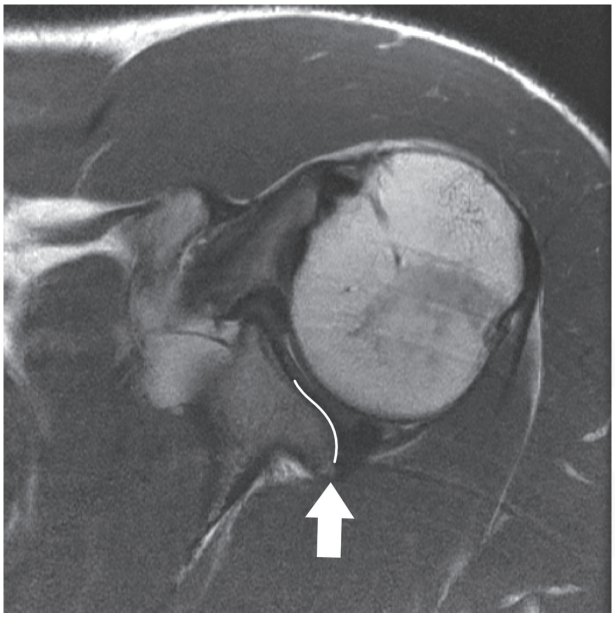


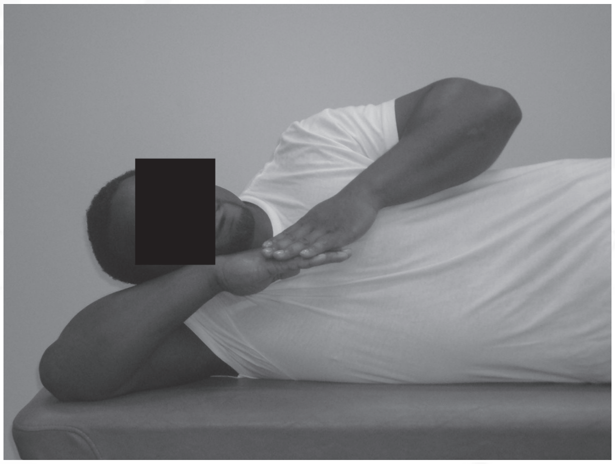
Figure 2. Axial fast-spin echo MRI of the left shoulder demonstrating deformation of the posterosuperior glenoid (line), with subchondral bony depression and remodeling (arrow), consistent with the presence of internal impingement.

Computed tomography (CT) scans are rarely indicated for imaging patients with internal impingement of the shoulder because the condition is mainly one of soft tissue changes that are better identified by MRI. However, CT is the gold standard for the diagnosis of humeral and glenoid version, a condition that is important in both internal impingement and rotator cuff tears.[46] Newer, 3-dimensional reconstructions of CT data have also proven useful for identifying osseous anatomy and adaptations.[47]

Treatment Strategy

Conservative management of internal impingement is an appropriate initial approach, particularly in patients who do not report an acute traumatic event. In early disease, the pain can be poorly localized, and the shoulder is stiff,[7] which should be treated with rest and nonsteroidal anti-inflammatory drugs. If the pain is more localized to the posterior shoulder, treatment options include avoidance of throwing for at least 4 to 6 weeks with appropriate physical therapy. The natural history of the condition was studied in 39 professional baseball pitchers who entered spring training with GIRD.[48] Over the course of the season, 60% of the athletes developed shoulder injuries that prevented them from pitching. Posterior shoulder stretching exercises can be employed as both a therapeutic and protective regimen.[15,48–51] Daily stretching routines in major league pitchers resulted in no innings lost to injury.[48] Daily posterior capsular stretching exercises in elite tennis players using the "sleeper stretch" resulted in an increase in internal rotation and total rotation of the shoulder, as well as 38% less incidence of shoulder injury (Figure 3).[50] However, caution must be taken when stretching the anterior capsule and inferior glenohumeral ligament because this may result in an exacerbation of anterior laxity, which could be pathologic. Four distinct phases of rehabilitation have been described (ranging from diminishing symptoms to plyometric strengthening), with the aim to improve anterior laxity by strengthening the dynamic shoulder stabilizers.[15] The importance of proper mechanics in young throwers is not to be overlooked as a preventative measure to the development of shoulder pain in athletes.

Figure 3. Sleeper stretch. This is performed to improve a posterior capsule contracture.



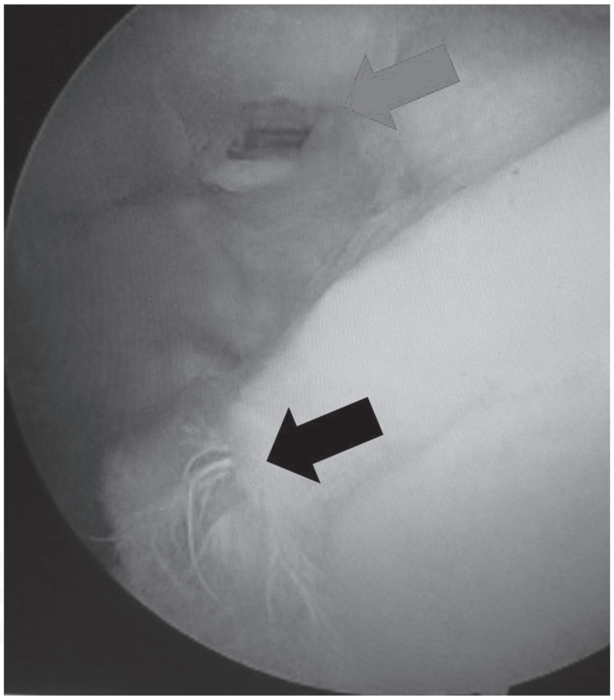
Injections of the shoulder have often been used as diagnostic tool for the Bennett lesion, typically using a local anesthetic.[52] The pain may be relieved with throwing, but may not be completely eliminated, suggesting the presence of concurrent pathology. To our knowledge, there have been no studies on the role of injections in internal impingement. Clinicians must exercise caution, especially in young, active patients, and must weigh the benefit of limiting the inflammatory cascade with the risk of permanent tendon damage.

Partial tears of the rotator cuff, as diagnosed by MRI, can occur with an adjacent tear and abrasion of the labrum; this constellation of findings is called a kissing lesion (Figure 4). Surgically, this can be managed by debridement or repair, with or without simultaneous acromioplasty. A general rule followed by surgeons is that tears $>$ 50% of the diameter require surgical repair. Following primary repair, both full- and partial-thickness rotator cuff tears perform and heal similarly on clinical follow-up.[53] Another method described for partial tears is to mobilize the soft tissues by completing the tear and performing a 2-row repair.[54,55]

The shoulder pathology in overhead athletes is not limited to the rotator cuff; patients may also present with posterosuperior labral detachment, degenerative labral changes, fraying and tenosynovitis of the biceps, and grades II to IV changes in the humeral head.[1,4,7,10,56] Studies have demonstrated an unsatisfactory outcome with this procedure in patients with posterior labral tears with increased anterior glenohumeral translation who underwent arthroscopic debridement alone.[57] Similarly poor results were noted in patients with known Bennett lesions who received arthroscopic removal of the lesion and rotator cuff debridement. The role of the Bennett lesion in both the etiology and treatment of internal impingement is not entirely clear. Earlier studies showed success with debridement of the lesion; however, a prospective cohort study of 16 baseball players with pain at the posterior shoulder relieved by local injection demonstrated that pain was improved or resolved after operative removal, although only 11 of the 16 players resumed previous activity.[28,52] Of those who with unsatisfactory outcomes, additional lesions were identified in the shoulder as the likely cause of symptoms.

The subtle anterior laxity that develops in the affected shoulder of patients with internal impingement has been identified as a cause of treatment failure. Jobe,[2] Andrews and Dugas,[29] and Montgomery and Jobe[30] recommend operative management of this joint laxity through anterior capsulolabral reconstruction, believing this may be the cause of the pathomechanics leading to further injury. Altchek and Dines[56] developed a less invasive procedure for capsular repair after concern for the morbidity of an open approach, aiming to restore capsular tension without functional range of motion limitations.

Figure 4. Arthroscopic view of a kissing lesion. Note the tear of the undersurface of the rotator cuff (gray arrow) and the fraying of the posterosuperior labrum (black arrow) where abnormal contact has taken place.



Most of the surgical options described are aimed at treating the soft tissue abnormalities associated with internal impingement, though some have investigated procedures focused on the bones of the shoulder. For example, Riand et al[58] described a derotational osteotomy with myorraphy of the subscapularis muscle as a treatment option. In these patients, the persistent pain after articular debridement was believed to be caused by increased humeral retroversion and prevented the patients from returning to their throwing sports. After the osteotomy, 55% of the patients were able to resume their sport at full level.

Summary

From the authors' perspective, the literature from the past 2 decades has demonstrated increasing awareness and knowledge of the causes of posterior shoulder pain and internal impingement of the shoulder. More data and long-term follow-up studies can be expected, especially investigating the different treatment options. To date, we know of no prospective studies directly comparing treatment modalities, which is a limitation of the current body of evidence. Most of the current studies are clinical follow-up, not comparative but observational in nature. The condition itself presents difficulties in study design because concomitant shoulder pathologies make matching groups for a study difficult. Anecdotally, the authors have observed increased glenoid retroversion, as described by Crockett et al[21] when comparing dominant to nondominant shoulders in throwers and nonthrowers. In the authors' opinion, the posterior glenoid shape remodeling may lead to a prominence of the posterior glenoid. There is then an increased risk of contact between the articular surface of the rotator cuff and the posterior glenoid margin. Our hypothesis is that this shape change of the glenoid contributes to the internal rotation deficit and may then lead to internal impingement. Though the role of glenoid retroversion in the natural history of the disease is currently unclear, further study may reveal this as a future target for treatment.

The repetitive motions essential to the sports of overhead athletes place supraphysiologic strains on the shoulder and may result in a variety of changes, including exostoses, capsular laxity, increased humeral retroversion, scapular muscle imbalance, and rotator cuff tendonitis. However, distinguishing between pathologic and adaptive processes is difficult for even the most experienced of surgeons. Initially, conservative treatment and nonoperative therapy should be attempted, but failure may result in the necessity of surgical intervention to allow the patient to resume high levels of competition. For the surgeon, the importance of addressing all comorbidities at the time of surgery cannot be understated, especially capsular laxity and contracture, as failure to do so has demonstrated poor outcomes. Looking to the future, further studies into the role of the Bennett lesion, glenoid version, and a standardized classification system of these shoulder injuries should help to improve our understanding of internal impingement the overhead athlete.

Conflict of Interest Statement

Steven Behrens, MD, Jeffrey Compas, BA, Matthew E. Deren, BS, and Mark Drakos, MD disclose no conflicts of interest.

References

1. Walch G, Boileau P, Noel E, Donell ST. Impingement of the deep surface of the supraspinatus tendon on the posterosuperior glenoid rim: an arthroscopic study. *J Shoulder Elbow Surg*. 1992;1:238–245.
2. Jobe CM. Posterior superior glenoid impingement: expanded spectrum. *Arthroscopy*. 1995;11(5):530–536.
3. Edelson G, Teitz C. Internal impingement in the shoulder. *J Shoulder Elbow Surg*. 2000;9(4):308–315.
4. Paley KJ, Jobe FW, Pink MM, Kvitne RS, ElAttrache NS. Arthroscopic findings in the overhand throwing athlete: evidence for posterior internal impingement of the rotator cuff. *Arthroscopy*. 2000;16(1):35–40.
5. Neer CS 2nd, Craig EV, Fukuda H. Cuff-tear arthropathy. *J Bone Joint Surg Am*. 1983;65(9):1232–1244.
6. Neer CS 2nd. Impingement lesions. *Clin Orthop Relat Res*. 1983;173: 70–77.
7. Jobe CM. Superior glenoid impingement. Current concepts. *Clin Orthop Relat Res*. 1996;330:98–107.
8. Bennett GE. Elbow and shoulder lesions of baseball players. *Am J Surg*. 1959;98:484–492.
9. Lombardo SJ, Jobe FW, Kerlan RK, Carter VS, Shields CL Jr. Posterior shoulder lesions in throwing athletes. *Am J Sports Med*. 1977;5(3): 106–110.
10. Andrews JR, Broussard TS, Carson WG. Arthroscopy of the shoulder in the management of partial tears of the rotator cuff: a preliminary report. *Arthroscopy*. 1985;1(2):117–122.
11. Jobe FW, Kvitne RS, Giangarra CE. Shoulder pain in the overhand or throwing athlete. The relationship of anterior instability and rotator cuff impingement. *Orthop Rev*. 1989;18(9):963–975.
12. Jobe FW, Giangarra CE, Kvitne RS, Glousman RE. Anterior capsulolabral reconstruction of the shoulder in athletes in overhand sports. *Am J Sports Med*. 1991;19(5):428–434.
13. Walch G, Liotard JP, Boileau P, Noel E. Postero-superior glenoid impingement. Another shoulder impingement [in French]. *Rev Chir Orthop Reparatrice Appar Mot*. 1991;77(8):571–574.
14. Kronberg M, Brostrom LA, Söderlund V. Retroversion of the humeral head in the normal shoulder and its relationship to the normal range of motion. *Clin Orthop Relat Res*. 1990;253:113–117.
15. Wilk KE, Meister K, Andrews JR. Current concepts in the rehabilitation of the overhead throwing athlete. *Am J Sports Med*. 2002;30(1):136–151.
16. Borich MR, Bright JM, Lorello DJ, Cieminski CJ, Buisman T, Ludewig PM. Scapular angular positioning at end range internal rotation in cases of glenohumeral internal rotation deficit. *J Orthop Sports Phys Ther*. 2006;36(12):926–934.

17. Laudner KG, Myers JB, Pasquale MR, Bradley JP, Lephart SM. Scapular dysfunction in throwers with pathologic internal impingement. *J Orthop Sports Phys Ther*. 2006;36(7):485–494.
18. Burkhart SS, Morgan CD. The peel-back mechanism: its role in producing and extending posterior type II SLAP lesions and its effect on SLAP repair rehabilitation. *Arthroscopy*. 1998;14(6):637–640.
19. Fleisig GS, Dillman CJ, Andrews JR. Biomechanics of the shoulder during throwing. In: *The Athlete's Shoulder*. New York, NY: Churchill Livingstone, 1994:360–365.
20. Levitz CL, Dugas J, Andrews JR. The use of arthroscopic thermal capsulorrhaphy to treat internal impingement in baseball players. *Arthroscopy*. 2001;17(6):573–577.
21. Crockett HC, Gross LB, Wilk KE, et al. Osseous adaptation and range of motion at the glenohumeral joint in professional baseball pitchers. *Am J Sports Med*. 2002;30(1):20–26.
22. Myers JB, Laudner KG, Pasquale MR, Bradley JP, Lephart SM. Glenohumeral range of motion deficits and posterior shoulder tightness in throwers with pathologic internal impingement. *Am J Sports Med*. 2006;34(3):385–391.
23. Osbahr DC, Cannon DL, Speer KP. Retroversion of the humerus in the throwing shoulder of college baseball pitchers. *Am J Sports Med*. 2002;30(3):347–353.
24. Grossman MG, Tibone JE, McGarry MH, Schneider DJ, Veneziani S, Lee TQ. A cadaveric model of the throwing shoulder: a possible etiology of superior labrum anterior-to-posterior lesions. *J Bone Joint Surg Am*. 2005;87(4):824–831.
25. Huffman GR, Tibone JE, McGarry MH, Phipps BM, Lee YS, Lee TQ. Path of glenohumeral articulation throughout the rotational range of motion in a thrower's shoulder model. *Am J Sports Med*. 2006;34(10):1662–1669.
26. Tirman PF, Feller JF, Janzen DL, Peterfy CG, Bergman AG. Association of glenoid labral cysts with labral tears and glenohumeral instability: radiologic findings and clinical significance. *Radiology*. 1994;190(3):653–658.
27. Meister K, Seroyer S. Arthroscopic management of the thrower's shoulder: internal impingement. *Orthop Clin North Am*. 2003;34(4):539–547.
28. Meister K, Andrews JR, Batts J, Wilk K, Baumgarten T. Symptomatic thrower's exostosis. Arthroscopic evaluation and treatment. *Am J Sports Med*. 1999;27(2):133–136.
29. Andrews JR, Dugas JR. Diagnosis and treatment of shoulder injuries in the throwing athlete: the role of thermal-assisted capsular shrinkage. *Instr Course Lect*. 2001;50:17–21.
30. Montgomery WH 3rd, Jobe FW. Functional outcomes in athletes after modified anterior capsulolabral reconstruction. *Am J Sports Med*. 1994;22(3):352–358.
31. Sonnery-Cottet B, Edwards TB, Noel E, Walch G. Results of arthroscopic treatment of posterosuperior glenoid impingement in tennis players. *Am J Sports Med*. 2002;30(2):227–232.
32. McFarland EG, Hsu CY, Neira C, O'Neil O. Internal impingement of the shoulder: a clinical and arthroscopic analysis. *J Shoulder Elbow Surg*. 1999;8(5):458–460.
33. Meister K, Buckley B, Batts J. The posterior impingement sign: diagnosis of rotator cuff and posterior labral tears secondary to internal impingement in overhand athletes. *Am J Orthop (Belle Mead NJ)*. 2004;33(8):412–415.
34. Matava MJ, Purcell DB, Rudzki JR. Partial-thickness rotator cuff tears. *Am J Sports Med*. 2005;33(9):1405–1417.
35. Connor PM, Banks DM, Tyson AB, Coumas JS, D'Alessandro DF. Magnetic resonance imaging of the asymptomatic shoulder of overhead athletes: a 5-year follow-up study. *Am J Sports Med*. 2003;31(5):724–727.
36. Yamanaka K, Matsumoto T. The joint side tear of the rotator cuff. A followup study by arthrography. *Clin Orthop Relat Res*. 1994;304:68–73.
37. Kaplan LD, McMahon PJ, Towers J, Irrgang JJ, Rodosky MW. Internal impingement: findings on magnetic resonance imaging and arthroscopic evaluation. *Arthroscopy*. 2004;20(7):701–704.
38. Halbrecht JL, Tirman P, Atkin D. Internal impingement of the shoulder: comparison of findings between the throwing and nonthrowing shoulders of college baseball players. *Arthroscopy*. 1999;15(3):253–258.
39. Ruotolo C, Price E, Panchal A. Loss of total arc of motion in collegiate baseball players. *J Shoulder Elbow Surg*. 2006;15(1):67–71.
40. Meister K. Internal impingement in the shoulder of the overhand athlete: pathophysiology, diagnosis, and treatment. *Am J Orthop (Belle Mead NJ)*. 2000;29(6):433–438.
41. Gross ML, Brenner SL, Esformes I, Sonzogni JJ. Anterior shoulder instability in weight lifters. *Am J Sports Med*. 1993;21(4):599–603.
42. Rokous JR, Feagin JA, Abbott HG. Modified axillary roentgenogram. A useful adjunct in the diagnosis of recurrent instability of the shoulder. *Clin Orthop Relat Res*. 1972;82:84–86.
43. Gusmer PB, Potter HG, Schatz JA, et al. Labral injuries: accuracy of detection with unenhanced MR imaging of the shoulder. *Radiology*. 1996;200(2):519–524.
44. Connell DA, Potter HG, Wickiewicz TL, Altchek DW, Warren RF. Noncontrast magnetic resonance imaging of superior labral lesions. 102 cases confirmed at arthroscopic surgery. *Am J Sports Med*. 1999;27(2):208–213.
45. Yamaguchi K, Ditsios K, Middleton WD, Hildebolt CF, Galatz LM, Teefey SA. The demographic and morphological features of rotator cuff disease. A comparison of asymptomatic and symptomatic shoulders. *J Bone Joint Surg Am*. 2006;88(8):1699–1704.
46. Tétreault P, Krueger A, Zurakowski D, Gerber C. Glenoid version and rotator cuff tears. *J Orthop Res*. 2004;22(1):202–207.
47. Kwon YW, Powell KA, Yum JK, Brems JJ, Iannotti JP. Use of three-dimensional computed tomography for the analysis of the glenoid anatomy. *J Shoulder Elbow Surg*. 2005;14(1):85–90.
48. Burkhart SS, Morgan CD, Kibler WB. The disabled throwing shoulder: spectrum of pathology Part III: The SICK scapula, scapular dyskinesis, the kinetic chain, and rehabilitation. *Arthroscopy*. 2003;19(6):641–661.
49. Burkhart SS, Morgan CD, Kibler WB. The disabled throwing shoulder: spectrum of pathology. Part II: evaluation and treatment of SLAP lesions in throwers. *Arthroscopy*. 2003;19(5):531–539.
50. Burkhart SS, Morgan CD, Kibler WB. The disabled throwing shoulder: spectrum of pathology Part I: pathoanatomy and biomechanics. *Arthroscopy*. 2003;19(4):404–420.
51. Bach HG, Goldberg BA. Posterior capsular contracture of the shoulder. *J Am Acad Orthop Surg*. 2006;14(5):265–277.
52. Yoneda M, Nakagawa S, Hayashida K, Fukushima S, Wakitani S. Arthroscopic removal of symptomatic Bennett lesions in the shoulders of baseball players: arthroscopic Bennett-plasty. *Am J Sports Med*. 2002;30(5):728–736.
53. Park JY, Yoo MJ, Kim MH. Comparison of surgical outcome between bursal and articular partial thickness rotator cuff tears. *Orthopedics*. 2003;26(4):387–390.
54. Lo IK, Burkhart SS. Double-row arthroscopic rotator cuff repair: re-establishing the footprint of the rotator cuff. *Arthroscopy*. 2003;19(9):1035–1042.
55. Meier SW, Meier JD. Rotator cuff repair: the effect of double-row fixation on three-dimensional repair site. *J Shoulder Elbow Surg*. 2006;15(6):691–696.
56. Altchek DW, Dines DM. Shoulder injuries in the throwing athlete. *J Am Acad Orthop Surg*. 1995;3(3):159–165.
57. Payne LZ, Altchek DW. The surgical treatment of anterior shoulder instability. *Clin Sports Med*. 1995;14(4):863–883.
58. Riand N, Levigne C, Renaud E, Walch G. Results of derotational humeral osteotomy in posterosuperior glenoid impingement. *Am J Sports Med*. 1998;26(3):453–459.2