Current Reviews in Musculoskeletal Medicine (2018) 11:55–62
https://doi.org/10.1007/s12178-018-9459-2

INJURIES IN OVERHEAD ATHLETES (J DINES AND C CAMP, SECTION EDITORS)

# Treatment of Partial Thickness Rotator Cuff Tears in Overhead Athletes

**Joseph N. Liu [1] · Grant H. Garcia [1] · Anirudh K. Gowd [1] · Brandon C. Cabarcas [1] · Michael D. Charles [1] · Anthony A. Romeo [1] · Nikhil N. Verma [1]**

Published online: 13 January 2018


## Abstract

**Purpose of Review** To review the etiology, classification, presentation, evaluation, treatment strategy, and outcomes in overhead athletes with partial thickness rotator cuff tears.

**Recent Findings** Despite advances in surgical repair techniques, return to play following surgical repair of partial rotator cuff tears remains modest at best.

**Summary** Overhead athletes may be particularly prone to rotator cuff pathology due to the supraphysiological strains within the tendon during the throwing motion, as well as mechanical stress with contact between the undersurface of the rotator cuff and the glenoid. The true prevalence of partial tears may be underestimated given the high incidence of asymptomatic tears. Both dynamic ultrasound and enhanced contrast MRI have improved our understanding of this pathology. For most overhead athletes, nonoperative management is the most common course. Despite advances in imaging, diagnosis, and surgical techniques, our ability to return these patients to their elite level is modest at best when nonoperative management fails and surgical treatment is performed. If a surgical route is needed, debridement alone is the most frequent procedure given concerns of over constraint and poor return to play with surgical repair of the partial thickness rotator cuff tear.

**Keywords** Partial rotator cuff tear · Overhead athletes

## Introduction

Rotator cuff pathology is a common etiology for pain and dysfunction in overhead athletes [1, 2], particularly in baseball players who have the highest incidence of rotator cuff complaints, and is also the most common reason for lost time of play [3, 4]. While our understanding of the etiology and clinical diagnosis of this pathology becomes more precise with advances in radiographic imaging and diagnostic techniques, the true incidence in this population is likely underappreciated given the high incidence of asymptomatic tendinopathy and partial thickness tears [5•, 6–8]. Nevertheless, surgical treatment, particularly in those without full thickness tears, remains controversial given the variability in outcomes and lack of predictable recovery and return to pre-injury levels of play [2, 9•, 10–20]. What also confounds these outcomes is the high incidence of concomitant labral pathology, as well as the lack of certainty over the role of subacromial impingement. The purpose of this manuscript is to review the etiology, classification, presentation, evaluation, treatment strategy, and outcomes in overhead athletes with partial thickness rotator cuff tears.

## Etiology

Historically, rotator cuff tears were thought to be a result of external or subacromial impingement [21]. In overhead athletes, advances in modern medicine have elucidated a multitude of factors that may play a role in rotator cuff pathology [22–24]. The high incidence of rotator cuff pathology in overhead athletes likely stems from the supraphysiological loads of up to 108% of bodyweight and humeral angular velocity upwards 7000°/s experienced during the throwing motion [25, 26]. The rotation of the arm during the throwing mechanism is the fastest recorded human movement. At the same time, studies of glenohumeral kinetics demonstrate up to 40% anterior joint

This article is part of the Topical Collection on *Injuries in Overhead Athletes*

✉ Joseph N. Liu
joseph_liu@rush.edu

[1] Section of Sports Medicine, Midwest Orthopaedics at Rush, 1611 West Harrison Street, Suite 200, Chicago, IL 60612, USA

translation during the late cocking phase and 80% body weight distraction on pitch delivery which may be additional contributory factors [26]. The resultant forces on the rotator cuff peak during follow through and deceleration and can lead to repetitive microtrauma on the relatively avascular tendon insertions, resulting in either articular-sided tears due to internal impingement or tensile failure due to overload of the rotator cuff itself [27–32]. Internal impingement, first described by Walch, results when the posterior undersurface of the supraspinatus tendon impinges on the greater tuberosity insertion on the posterosuperior glenoid rim and typically occurs in overhead athletes in the late cocking and early acceleration phases of throwing (Fig. 1) [32]. In athletes with appropriate training, conditioning, and moderation of maximum throwing velocity, the rotator cuff can function successfully and adapt without injury. Improper mechanics, fatigue, and overload from overtraining and maximum effort throwing can result in a sequence of microinstability, where the rotator cuff is unable to maintain the humeral head in a centered position on the glenoid leading to internal impingement, rotator cuff overload, and, in some athletes, partial to full thickness rotator cuff tears.

## Partial Rotator Cuff Tear Classification

Codman first described the types of partial rotator cuff tears in 1934 [33]:

### Articular-Sided Tears

The most common type of partial rotator cuff tears in overhead athletes is articular-sided injuries [27, 34–36]. These tears usually involve the posterior supraspinatus and superior infraspinatus [2, 6, 27, 37]. While internal impingement undoubtedly plays a significant role in the prevalence of articular-sided tears in these athletes, other explanations include the relative hypovascularity of the articular tendon as it approaches the humeral attachment, as well as the fact that the collagen fibers on the articular side of the rotator cuff may be more randomly oriented, resulting in a lower overall strength compared to the bursal side [24, 38, 39]. Snyder coined the acronym partial articular-sided tendon avulsions as "PASTA" lesions as a separate and unique clinical entity when discussing rotator cuff tear patterns [14].

### Intra-Tendinous Tears

A natural extension of Snyder's PASTA lesion was described by both Yamanaka, Fukuda, and Conway [2, 39, 40]. Conway separated a variation of a PASTA lesion into a tear where the footprint appears to be intact, but there is a partial thickness articular surface intra-tendinous lesion, and coined the term PAINT lesion for this pathology. Recent studies have

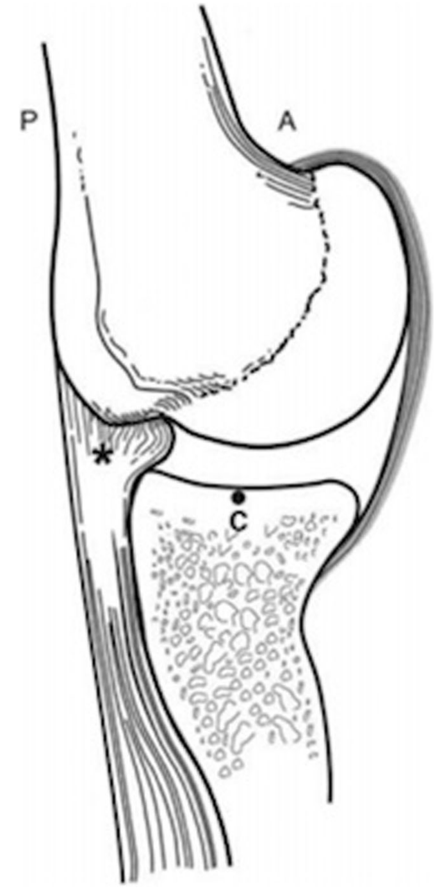


**Fig. 1** Internal impingement of the shoulder in abduction and external rotation. (A, anterior; P, posterior; C, glenohumeral center of rotation). Reprinted with permission from Burkhart et al. [3]

demonstrated that this unique entity may require different fixation than standard partial or full thickness tears [2, 22], although longer term clinical results and tendon healing studies are absent.

### Bursal-Sided Tears

Bursal-sided tears are less commonly found in overhead throwers and young athletes. Typically, these are more associated with external or subacromial impingement [21] and seen in chronic degeneration affected by the aging process. Associated glenohumeral pathology is commonly seen associated with bursal-sided tears, just as it is common with articular-sided tears in overhead athletes.

## Evaluation

### History

A detailed history is necessary to evaluate any shoulder pathology; however, there can be a surprising range of variation in an overhead athlete's chief complaint with respect to labral and rotator cuff pathology. These complaints may range from chronic pain to decreased velocity to mild pain at the tail end of a game [18]. While the majority of complaints may be insidious in onset, the athlete may also experience a "pop" (which may represent an acute tear of the tendon or labrum). One may also assess the presence of prior shoulder symptoms such as instability, decreased pitch control, or early fatigue [12]; however, the absence of these symptoms does not rule out rotator cuff pathology.

## Physical Exam

Examination of shoulder pain in an overhead athlete can be difficult given a strong association with concomitant pathologies. A standard shoulder exam should begin with a cervical exam to rule out underlying referred or radicular pain. Inspection of the shoulder girdle muscles is performed to identify atrophy in the supraspinatus or infraspinatus fossa. Additionally, the presence or absence of scapular dyskinesia should be carefully inspected as this may result from chronic shoulder injury or underlying neurologic injury. Specific palpation of various structures such as the acromioclavicular joint and biceps tendon is also required; posterior tenderness may indicate infraspinatus or intra-articular pathology.

All components of the rotator cuff including supraspinatus, infraspinatus, teres minor, and subscapularis are examined with tests designed to better isolate their function. Weakness in external rotation may suggest infraspinatus involvement, while subscapularis can be tested with the bear hug, belly press, or lift off signs. True assessment of the supraspinatus requires adequate scapular stabilization and the arm in a position outside of the impingement zone, such as the described champagne toast test [41, 42]. Impingement signs such as Neer and Hawkins may be positive; however, these signs are less specific for isolated rotator cuff pathology [43, 44]. The classic "shrug sign" which usually depicts weakness of the rotator cuff may be present when a patient elevates their scapula during shoulder abduction particularly in full thickness tears [45]. A lag sign may also be present in overhead athletes with an acute contusion or tear of the supraspinatus [46]. In many cases, overhead athletes may have preservation of their strength; however, those with partial tears may have pain with specific testing of their rotator cuff function.

Overhead athletes typically have a unique adaption of their range of motion of their dominant throwing arm; this usually results in an increase in external rotation at 90° of abduction, often beyond 100° of external rotation, and a relative decrease in internal rotation. When the loss of internal rotation compared to the contralateral side exceeds 25°, this deficit is termed glenohumeral internal rotation deficit (GIRD), which is also commonly associated with internal impingement [47]. However, since the throwing shoulder will undergo adaptive changes with increased retroversion of the glenoid, the difference in internal rotation between shoulder may be substantial but normal. Another assessment of the loss of motion that may be even more predictable for the risk of future injury is the change in the total arc of motion when compared to the contralateral shoulder motion.

Specific tests for internal impingement include the internal impingement sign, modified relocation testing, or internal rotation resistance testing [48–50]. As partial tears can often develop in the presence of posterior capsule contracture and superior translation of the humeral head, it is often difficult to distinguish on physical examination between pure internal impingement and internal impingement with concomitant partial rotator cuff tears.

## Imaging

Plain radiographs are standard in the initial evaluation of any shoulder pathology. While the sensitivity of plain radiographs for rotator cuff pathology may be low, subtle signs may be elucidated. These include cystic or sclerotic changes in the tuberosity as well as evaluation of the acromial morphology on the outlet view [51]. The critical shoulder angle which relates to the relationship of the lateral acromion and glenoid may also provide the suggestion of rotator cuff problems. Notching and cystic changes have been associated with articular-sided rotator cuff tears; however, the absence of these signs does not preclude the presence of rotator cuff pathology.

Magnetic resonance imaging (MRI) has become the most widely used method of diagnosing rotator cuff pathology, with excellent sensitivity in the diagnosis of full thickness tears. The ability of MRI to distinguish between partial thickness tears and tendinosis, however, can be challenging. While some studies have reported a high sensitivity and specificity for diagnosing partial tears, others have reported an equally high rate of false negative with arthroscopically proven partial articular-sided rotator cuff tears [52–54]. In these cases of uncertainty, MR arthrogram (MRA) particularly with the arm and abduction and external rotation may add significant diagnostic value to the detection of partial undersurface and intra-substance tears (Fig. 2) [10]. In fact, the authors recommend the abduction external rotation series in all overhead athletes, with or without intra-articular injection, to better evaluate the area of potential internal impingement. Nevertheless, definitive diagnosis using MRI must be met with a degree of caution, as many studies have demonstrated a high incidence of asymptomatic MRI diagnosed rotator cuff tears in overhead athletes [1, 5•]. Even the tears that are mildly symptomatic are usually clinically irrelevant as the athlete does not experience enough pain or impaired ability to desire surgical treatment. Additionally, when obtained too acutely, there may be artificial rotator cuff signal in overhead athletes suggesting a more significant zone of injury that does not resolve back to baseline until almost 1 week after competition [18].

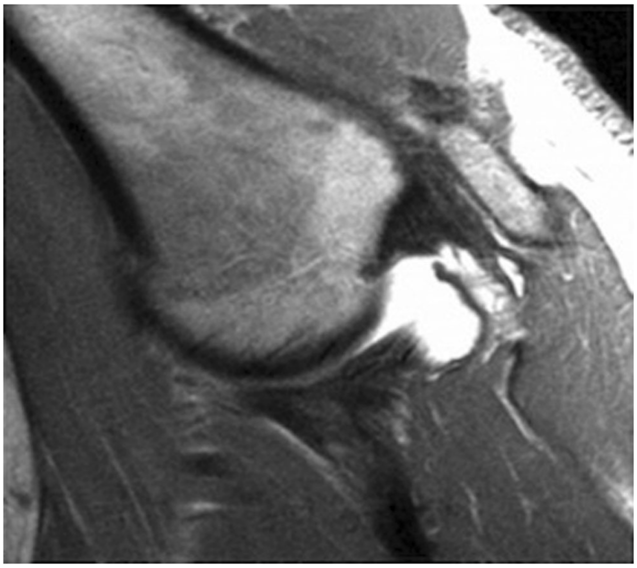

**Fig. 2** Intra-tendinous partial thickness rotator cuff tear in 90° of abduction and external rotation. Reprinted with permission from Brockmeier et al. [10]

While some studies have suggested that ultrasound may be as sensitive and specific as MRI in the detection of rotator cuff pathology, the effectiveness is user operator-dependent [6, 55, 56]. For practical purposes and consistency of evaluation, MRI remains the gold standard for imaging the rotator cuff tendon, muscle, and surrounding structures. MRI has a strong benefit in the ability to assess other concomitant pathology, including the presence or absence of labral or biceps pathology.

## Treatment Strategy

Nonoperative treatment is indicated for the initial treatment of partial rotator cuff tears in overhead athletes. Many partial tears are asymptomatic in overhead throwers, and the tears that do result in symptoms are often effectively treated without surgical repair. Furthermore, surgical repair of rotator cuff tendons in overhead athletes fails to return them to the same level of performance in more than 50% of the cases. The frequent improvement with nonoperative management as well as the high failure of return to same performance helps to focus the treatment on a variety of nonoperative principles such as reestablishing normal range of motion, strengthening the entire kinetic chain, scapula dyskinesia prevention, and adjustments in pitching mechanics.

Nonoperative treatment begins with a cessation from all throwing activities, anti-inflammatory medication for pain control, and physical therapy with an emphasis on range of motion and rotator cuff strengthening. Internal rotation deficits and posterior capsule contractures can be addressed with the sleeper stretch as well as cross-body adduction in variable planes [3]. Once shoulder symptoms improve, which may be facilitated with a corticosteroid injection at times, physical therapy can progress to a sports-specific training program, as well as initiating an interval throwing program with sport-specific movements. Duration of nonoperative therapy typically lasts 2–3 months when successful at resolving the presenting symptoms and may depend on level of play that the athlete wishes to return to [57].

Operative management is reserved for overhead athletes that have failed well-organized, consistent, nonoperative management. However, prior to operative management, an extensive discussion between the athlete and surgeon must take place given the moderate rates of return to throwing at pre-injury levels and elite performance [57, 58•]. Options for operative management of partial rotator cuff tears include both debridement and repair. Concomitant procedures include subacromial decompression and/or labral work may also be required, and while they may be anticipated based on preoperative assessment, the final decision typically comes at the time of the thorough arthroscopic evaluation of the glenohumeral joint and subacromial space. Ultimately, patient age, tissue quality, depth and involvement of the tear, and surgical experience come into play when finalizing the surgical plan. A repair may be indicated in any symptomatic full thickness tears and partial tears exceeding 75% of the tendon thickness [18]. Given some of the unpredictability involved with surgical repair, all options should be discussed and explanations based on evidence-based medicine should be given. Debridement of partial thickness tears should be the primary default pattern of the surgeon who cares for these athletes as frequently this resolves their pain and allows them to return to their sport at a higher level than athletes who have a surgical repair of the torn tendon. Clear and accurate explanations of the pathology, the treatment, and the expected outcomes in these elite athletes lead to the best satisfaction post-operatively. In caring for athletes involved in a professional or collegiate team, or other high-level competition, discussion with the player's trainers, coaches, and agents is necessary before embarking on surgery.

### Arthroscopic Debridement

Debridement of loose flaps or irregular tendon edges not only can remove tissue that generates pain but also allow assessment and evaluation of the full extent of the tear. Articular-sided tears are typically debrided with a mechanical shaver to remove all unhealthy tissue. When intra-tendinous extension (PAINT lesion) is present, more extensive debridement may be also required to allow for healing of the delaminated tissue. After debridement from the glenohumeral side is completed, a suture should be placed through the partially torn tissue for easy localization of the tear from the bursal side. An 18-gauge needle is advanced through the skin at the lateral edge of the acromion, through the deltoid, and then through the affected area of the rotator cuff tendon while visualizing from the articular surface. An absorbable colored suture is passed through the needle and out of the anterior portal. The procedure is then progress to the subacromial space and the suture is identified and protected during the bursectomy. An effort is made to achieve a "room with a view," establishing a presence in the center of the bursa, which helps to avoid unnecessary debridement and possibly cutting the suture. If clear evidence of mechanical impingement is present in the subacromial space such as bursal-sided abrasion to the rotator cuff tendon, an acromioplasty is performed. If a full thickness tear is not identified, or more than 25% of the tendon remains on the bursal side, no repair is performed. Again, the default should be towards debridement and not repair in the majority of partial thickness rotator cuff tears in the overhead athlete.

## Arthroscopic Repair of Partial Thickness Rotator Cuff Tears

Concerns for tear progression and modest outcomes after arthroscopic debridement may incline both surgeons and players to pursue operative repair of partial thickness rotator cuff tears after failed nonoperative therapy, or after failure to achieve the expected results with a previous arthroscopic debridement. Partial thickness tears of greater than 75% are typically repaired [18]; however, it is well-known that some high level professional pitchers continue to be effective despite documented full thickness rotator cuff tears [18]. In the general population, the 50% threshold has been typically cited for deciding between debridement and repair, with tears involving less than 50% of the tendon footprint being debrided and tears involving greater than 50% of the tendon footprint generally requiring repair. The evidence for this criterion is weak, and based on our experience with an athletic population, we routinely treat partial thickness rotator cuff tears with debridement, unless they are > 75% or demonstrate a large intratendinous component which is usually identified on preoperative MRI and confirmed at the time of arthroscopy. This threshold is lower for bursal-sided tears which often have a mechanical component such as clicking or catching with the arm abducted [15]. Given the tendency to constrain the joint with classic repair techniques, a threshold of 75% has been suggested for repair in overhead athletes [18]. The decision to perform a repair in this setting may be influenced by an athlete's age and other coexistent pathology.

We suggest an arthroscopic approach to repair partial tendon tears given the lower risk of stiffness and improved ability to recreate the anatomic footprint. For most partial tears that require repair, we perform a transosseous equivalent double row repair, which has demonstrated both increased strength and improved footprint coverage with resistance to cyclic loading compared to standard single row techniques (Fig. 3) [59]. Furthermore, although clinical outcomes are generally the same as single row repairs, there is a strong tendency towards a higher tendon-to-bone healing rate with double row repairs, which is a principle goal of the procedure. An important technique tip for repair techniques in overhead athletes is to avoid the tendency to over constrain the joint, as subclinical loss of range of motion, particularly in external rotation, may significantly affect return to play and ability to perform throw overhead. With tears in the zone of internal impingement at the posterior supraspinatus-anterior infraspinatus junction, the repair is performed in the area of the exposed lateral footprint, not immediately adjacent to the articular edge which can constrain motion. Tear completion is performed if a bursal-sided injury that is 90% or more of the tendon is found; a double row transosseous equivalent is our preferred method of fixation. However, for smaller thickness bursal-sided tears where the articular capsule and articular side of the tendon remain intact, this will act as the medial row fixation so that only a single row repair of the remaining tendon is performed. For articular-sided injuries, the bursal side may be kept intact as a checkrein to avoid over constraint, and a transtendon technique can be performed where only the articular-sided fibers are advanced to repair the articular footprint. Since most surgically repaired articular-sided tears are 75% of the thickness or greater, often, the best strategy for secure repair is to complete the tear and perform a double row transosseous repair, which we prefer to do with a knotless technique. For intra-tendinous tears, delaminated layers may be plicated and then advanced using suture anchors.

## Treatment Outcomes

Outcomes after debridement for partial thickness tears are generally successful in alleviating symptoms in non-throwing athletes [14, 15]. For high level overhead athletes, the results are not predictable. While there may be a high level of satisfaction of up to 85–90% with daily pain relief and return to activities, the results for overhead athletes remain undesirable. Return to sport rates can be 75% or greater, but return to pre-injury level of performance is usually less than 50%. For professional pitchers, only 45–76% return to prior level of play has been achieved, with most studies towards the lower rate [13, 19, 20]. Reynolds et al. evaluated 82 professional throwers treated with debridement alone for partial thickness rotator cuff tears [13]. In this study, they demonstrated 76% return to Major League Baseball play, but only 55% returning to their prior level of performance. In another study, Payne et al. reported on 43 young overhead athletes who underwent debridement for partial rotator cuff tears [20]. At 2-year follow-up, they reported only 45% return to pre-injury sports.

Similarly, while the results of partial tendon repair have been excellent in the general population, the results have not been universally positive in the overhead athletes. Rates of return to sports have ranged from 33 to 89% [2, 16–18]. Ide

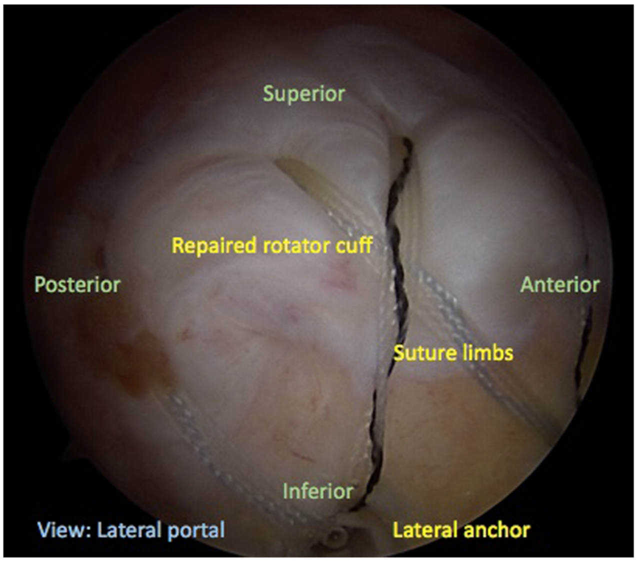


**Fig. 3** Final arthroscopic transosseous equivalent repair viewing from direct lateral portal

et al. reported a 33% return to same or higher level of play in six overhead athletes who underwent transtendinous repair [16]. Conway et al. had improved success with 14 elite throwers following repair of their partial tendon tears, with 89% returning to their previous level of play [2]. This level of success in elite throwing athletes has not been achieved in all other studies.

## Conclusions

The prevalence of partial rotator cuff pathology in overhead athletes is common, with many athletes competing with partial thickness rotator cuff tears. Those athletes with partial thickness tears that become symptomatic and fail nonoperative treatment may be candidates for surgery, although this path should be reluctantly followed with most efforts at treatment focused on nonsurgical options. Typically, debridement is reserved for patients with less than 75% involvement of the tendon. Repair may be indicated for patients with greater than 75% of tendon involvement. Unfortunately, the return rates to the same level of performance following arthroscopic repair are modest at best for elite overhead athletes. Thus, an extensive discussion of the risks, benefits, and likelihood of return to pre-injury level of play must be done preoperatively. Further research is needed to develop better strategies for preventing symptomatic partial thickness rotator cuff tears, as well as better tools to diagnosis and treat this unique patient population with the goal of returning them back to their pre-injury level of competition and performance.

## Compliance with Ethical Standards

**Conflict of Interest** Anthony A. Romeo reports American Orthopaedic Society for Sports Medicine: Board or committee member. American Shoulder and Elbow Surgeons: Board or committee member. Orthopedics: Editorial or governing board. Orthopedics Today: Board or committee member; Editorial or governing board. SAGE: Editorial or governing board. SLACK Incorporated: Editorial or governing board. Wolters Kluwer Health - Lippincott Williams & Wilkins: Editorial or governing board.

Nikhil N. Verma reports American Orthopaedic Society for Sports Medicine: Board or committee member. American Shoulder and Elbow Surgeons: Board or committee member. Arthroscopy Association Learning Center Committee: Board or committee member. Arthroscopy: Editorial or governing board. Journal of Knee Surgery: Editorial or governing board. SLACK Incorporated: Editorial or governing board.

All other authors declare that they have no conflict of interest.

**Human and Animal Rights and Informed Consent** This article does not contain any studies with human or animal subjects performed by any of the authors.

## References

Papers of particular interest, published recently, have been highlighted as:
• Of importance


1. 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):724–7. https://doi.org/10.1177/03635465030310051501.
2. Conway JE. Arthroscopic repair of partial-thickness rotator cuff tears and SLAP lesions in professional baseball players. Orthop Clin N Am. 2001;32(3):443–56. https://doi.org/10.1016/S0030-5898(05)70213-3.
3. Burkhart SS, Morgan CD, Kibler WB. The disabled throwing shoulder: spectrum of pathology Part I: pathoanatomy and biomechanics. Arthroscopy. 2003;19(4):404–20. https://doi.org/10.1053/jars.2003.50128.
4. McFarland EG, Wasik M. Epidemiology of collegiate baseball injuries. Clin J Sport Med. 1998;8(1):10–3. https://doi.org/10.1097/00042752-199801000-00003.
5.• Del Grande F, Aro M, Jalali Farahani S, Cosgarea A, Wilckens J, Carrino JA. High-resolution 3-T magnetic resonance imaging of the shoulder in nonsymptomatic professional baseball pitcher draft picks. J Comput Assist Tomogr. 2016;40(1):118–25. **Study demonstrating high incidence of tendinopathy and partial tears in asymptomatic baseball players**. https://doi.org/10.1097/RCT.0000000000000327.
6. Teefey SA, Rubin DA, Middleton WD, Hildebolt CF, Leibold RA, Yamaguchi K. Detection and quantification of rotator cuff tears. Comparison of ultrasonographic, magnetic resonance imaging, and arthroscopic findings in seventy-one consecutive cases. J Bone Joint Surg Am. 2004;86-A(4):708–16.
7. Miniaci A, Mascia AT, Salonen DC, Becker EJ. Magnetic resonance imaging of the shoulder in asymptomatic professional baseball pitchers. Am J Sports Med. 2002;30(1):66–73. https://doi.org/10.1177/03635465020300012501.
8. Lesniak BP, Baraga MG, Jose J, Smith MK, Cunningham S, Kaplan LD. Glenohumeral findings on magnetic resonance imaging correlate with innings pitched in asymptomatic pitchers. Am J Sports

Med. 2013;41(9):2022–7. https://doi.org/10.1177/0363546513491093.

9.• Dines JS, Jones K, Maher P, Altchek D. Arthroscopic management of full-thickness rotator cuff tears in Major League Baseball pitchers: the lateralized footprint repair technique. Am J Orthop (Belle Mead NJ). 2016;45(3):128–33. **Case series describing high rate of return to sport for professional baseball pitchers after surgical repair of full-thickness rotator cuff tears using lateralized footprint repair technique**.

10. Brockmeier SF, Dodson CC, Gamradt SC, Coleman SH, Altchek DW. Arthroscopic intratendinous repair of the delaminated partial-thickness rotator cuff tear in overhead athletes. Arthroscopy. 2008;24(8):961–5. https://doi.org/10.1016/j.arthro.2007.08.016.

11. Liem D, Lichtenberg S, Magosch P, Habermeyer P. Arthroscopic rotator cuff repair in overhead-throwing athletes. Am J Sports Med. 2008;36(7):1317–22. https://doi.org/10.1177/0363546508314794.

12. Mazoue CG, Andrews JR. Repair of full-thickness rotator cuff tears in professional baseball players. Am J Sports Med. 2006;34(2):182–9. https://doi.org/10.1177/0363546505279916.

13. Reynolds SB, Dugas JR, Cain EL, McMichael CS, Andrews JR. Debridement of small partial-thickness rotator cuff tears in elite overhead throwers. Clin Orthop Relat Res. 2008;466(3):614–21. https://doi.org/10.1007/s11999-007-0107-1.

14. Snyder SJ, Pachelli AF, Del Pizzo W, Friedman MJ, Ferkel RD, Pattee G. Partial thickness rotator cuff tears: results of arthroscopic treatment. Arthroscopy. 1991;7(1):1–7. https://doi.org/10.1016/0749-8063(91)90070-E.

15. Cordasco FA, Backer M, Craig EV, Klein D, Warren RF. The partial-thickness rotator cuff tear: is acromioplasty without repair sufficient? Am J Sports Med. 2002;30(2):257–60. https://doi.org/10.1177/03635465020300021801.

16. Ide J, Maeda S, Takagi K. Arthroscopic transtendon repair of partial-thickness articular-side tears of the rotator cuff: anatomical and clinical study. Am J Sports Med. 2005;33(11):1672–9. https://doi.org/10.1177/0363546505277141.

17. Van Kleunen JP, Tucker SA, Field LD, Savoie FH III. Return to high-level throwing after combination infraspinatus repair, SLAP repair, and release of glenohumeral internal rotation deficit. Am J Sports Med. 2012;40(11):2536–41. https://doi.org/10.1177/0363546512459481.

18. Shaffer B, Huttman D. Rotator cuff tears in the throwing athlete. Sports Med Arthrosc Rev. 2014;22(2):101–9. https://doi.org/10.1097/JSA.0000000000000022.

19. 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):117–22. https://doi.org/10.1016/S0749-8063(85)80041-4.

20. Payne LZ, Altchek DW, Craig EV, Warren RF. Arthroscopic treatment of partial rotator cuff tears in young athletes. A preliminary report. Am J Sports Med. 1997;25(3):299–305. https://doi.org/10.1177/036354659702500305.

21. CHARLES S, NEER I. Anterior acromioplasty for the chronic impingement syndrome in the shoulder: a preliminary report. JBJS. 1972;54(1):41–50.

22. Nho SJ, Yadav H, Shindle MK, MacGillivray JD. Basic science update: rotator cuff degeneration: etiology and pathogenesis. Am J Sports Med. 2008;36(5):987–93. https://doi.org/10.1177/0363546508317344.

23. Mazzocca AD, Rincon LM, O'Connor RW, Obopilwe E, Andersen M, Geaney L, et al. Intra-articular partial-thickness rotator cuff tears: analysis of injured and repaired strain behavior. Am J Sports Med. 2008;36(1):110–6. https://doi.org/10.1177/0363546507307502.

24. Lohr JF, Uhthoff HK. The microvascular pattern of the supraspinatus tendon. Clin Orthop Relat Res. 1990;254(254):35–8.

25. Werner SL, Gill TJ, Murray TA, Cook TD, Hawkins RJ. Relationships between throwing mechanics and shoulder distraction in professional baseball pitchers. Am J Sports Med. 2001;29(3):354–8. https://doi.org/10.1177/03635465010290031701.

26. Dillman CJ, Fleisig GS, Andrews JR. Biomechanics of pitching with emphasis upon shoulder kinematics. J Orthop Sports Phys Ther. 1993;18(2):402–8. https://doi.org/10.2519/jospt.1993.18.2.402.

27. Ryu RK, Burkhart SS, Parten PM, Gross RM. Complex topics in arthroscopic subacromial space and rotator cuff surgery. Arthroscopy. 2002;18(2 Suppl 1):51–64. https://doi.org/10.1053/jars.2002.31798.

28. Kuhn JE, Bey MJ, Huston LJ, Blasier RB, Soslowsky LJ. Ligamentous restraints to external rotation of the humerus in the late-cocking phase of throwing. A cadaveric biomechanical investigation. Am J Sports Med. 2000;28(2):200–5. https://doi.org/10.1177/03635465000280021001.

29. Rathbun JB, Macnab I. The microvascular pattern of the rotator cuff. J Bone Joint Surg (Br). 1970;52(3):540–53.

30. Jobe CM. Posterior superior glenoid impingement: expanded spectrum. Arthroscopy. 1995;11(5):530–6. https://doi.org/10.1016/0749-8063(95)90128-0.

31. Jobe FW, Moynes DR, Tibone JE, Perry J. An EMG analysis of the shoulder in pitching. A second report. Am J Sports Med. 1984;12(3):218–20. https://doi.org/10.1177/036354658401200310.

32. 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 Elb Surg. 1992;1(5):238–45. https://doi.org/10.1016/S1058-2746(09)80065-7.

33. Codman EA. The shoulder; rupture of the suprasupinatus tendon and other lesions in or about the subacromial bursa. 1934.

34. Ellman H. Diagnosis and treatment of incomplete rotator cuff tears. Clin Orthop Relat Res. 1990;254(254):64–74.

35. Weber SC. Arthroscopic debridement and acromioplasty versus mini-open repair in the management of significant partial-thickness tears of the rotator cuff. Orthop Clin N Am. 1997;28(1):79–82. https://doi.org/10.1016/S0030-5898(05)70266-2.

36. Itoi E, Tabata S. Incomplete rotator cuff tears. Results of operative treatment. Clin Orthop Relat Res. 1992;284(284):128–35.

37. Matava MJ, Purcell DB, Rudzki JR. Partial-thickness rotator cuff tears. Am J Sports Med. 2005;33(9):1405–17. https://doi.org/10.1177/0363546505280213.

38. Clark JM, Harryman DT II. Tendons, ligaments, and capsule of the rotator cuff. Gross and microscopic anatomy. J Bone Joint Surg Am. 1992;74(5):713–25. https://doi.org/10.2106/00004623-199274050-00010.

39. Fukuda H, Hamada K, Nakajima T, Tomonaga A. Pathology and pathogenesis of the intratendinous tearing of the rotator cuff viewed from en bloc histologic sections. Clin Orthop Relat Res. 1994;304(304):60–7.

40. Yamanaka K, Matsumoto T. The joint side tear of the rotator cuff. A followup study by arthrography. Clin Orthop Relat Res. 1994;304(304):68–73.

41. Chalmers PN, Cvetanovich GL, Kupfer N, Wimmer MA, Verma NN, Cole BJ, et al. The champagne toast position isolates the supraspinatus better than the Jobe test: an electromyographic study of shoulder physical examination tests. J Shoulder Elb Surg. 2016;25(2):322–9. https://doi.org/10.1016/j.jse.2015.07.031.

42. Kibler WB, Sciascia A, Dome D. Evaluation of apparent and absolute supraspinatus strength in patients with shoulder injury using the scapular retraction test. Am J Sports Med. 2006;34(10):1643–7. https://doi.org/10.1177/0363546506288728.

43. Park HB, Yokota A, Gill HS, El Rassi G, McFarland EG. Diagnostic accuracy of clinical tests for the different degrees of

subacromial impingement syndrome. J Bone Joint Surg Am. 2005;87(7):1446–55. https://doi.org/10.2106/JBJS.D.02335.

44. MacDonald PB, Clark P, Sutherland K. An analysis of the diagnostic accuracy of the Hawkins and Neer subacromial impingement signs. J Shoulder Elb Surg. 2000;9(4):299–301. https://doi.org/10.1067/mse.2000.106918.
45. Blevins FT. Rotator cuff pathology in athletes. Sports Med. 1997;24(3):205–20. https://doi.org/10.2165/00007256-199724030-00009.
46. Hertel R, Ballmer FT, Lombert SM, Gerber C. Lag signs in the diagnosis of rotator cuff rupture. J Shoulder Elb Surg. 1996;5(4):307–13. https://doi.org/10.1016/S1058-2746(96)80058-9.
47. Wilk KE, Macrina LC, Fleisig GS, Porterfield R, Simpson CD 2nd, Harker P, et al. Correlation of glenohumeral internal rotation deficit and total rotational motion to shoulder injuries in professional baseball pitchers. Am J Sports Med. 2011;39(2):329–35. https://doi.org/10.1177/0363546510384223.
48. Zaslav KR. Internal rotation resistance strength test: a new diagnostic test to differentiate intra-articular pathology from outlet (Neer) impingement syndrome in the shoulder. J Shoulder Elb Surg. 2001;10(1):23–7. https://doi.org/10.1067/mse.2001.111960.
49. Meister K. Current concepts. Injuries to the shoulder in the throwing athlete. Part two: evaluation/treatment. Am J Sports Med. 2000;28(4):587–601. https://doi.org/10.1177/03635465000280042701.
50. Hamner DL, Pink MM, Jobe FW. A modification of the relocation test: arthroscopic findings associated with a positive test. J Shoulder Elb Surg. 2000;9(4):263–7. https://doi.org/10.1067/mse.2000.105450.
51. Pearsall AW, Bonsell S, Heitman RJ, Helms CA, Osbahr D, Speer KP. Radiographic findings associated with symptomatic rotator cuff tears. J Shoulder Elb Surg. 2003;12(2):122–7. https://doi.org/10.1067/mse.2003.19.
52. Gartsman GM, Taverna E. The incidence of glenohumeral joint abnormalities associated with full-thickness, reparable rotator cuff tears. Arthroscopy. 1997;13(4):450–5. https://doi.org/10.1016/S0749-8063(97)90123-7.
53. Gartsman GM, Milne JC. Articular surface partial-thickness rotator cuff tears. J Shoulder Elb Surg. 1995;4(6):409–15. https://doi.org/10.1016/S1058-2746(05)80031-X.
54. Traughber PD, Goodwin TE. Shoulder MRI: arthroscopic correlation with emphasis on partial tears. J Comput Assist Tomogr. 1992;16(1):129–33.
55. van Holsbeeck MT, Kolowich PA, Eyler WR, Craig JG, Shirazi KK, Habra GK, et al. US depiction of partial-thickness tear of the rotator cuff. Radiology. 1995;197(2):443–6. https://doi.org/10.1148/radiology.197.2.7480690.
56. Iannotti JP, Ciccone J, Buss DD, Visotsky JL, Mascha E, Cotman K, et al. Accuracy of office-based ultrasonography of the shoulder for the diagnosis of rotator cuff tears. J Bone Joint Surg Am. 2005;87(6):1305–11. https://doi.org/10.2106/JBJS.D.02100.
57. Plate JF, Haubruck P, Walters J, Mannava S, Smith BP, Smith TL, et al. Rotator cuff injuries in professional and recreational athletes. J Surg Orthop Adv. 2013;22(2):134–42. https://doi.org/10.3113/JSOA.2013.0134.
58.• Reuter S, Imhoff AB, Martetschlager F. Impact of rotator cuff surgery on postoperative sporting activity. J Sports Med Phys Fitness. 2016. **Systematic review reporting on return to sport for recreational and professional athletes**.
59. Lo IK, Burkhart SS. Transtendon arthroscopic repair of partial-thickness, articular surface tears of the rotator cuff. Arthroscopy. 2004;20(2):214–20. https://doi.org/10.1016/j.arthro.2003.11.042.