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Rotator Cuff Injuries in Tennis Players

Rami G. Alrabaa [1] · Mario H. Lobao [1] · William N. Levine [1]

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Abstract

Purpose of Review This review presents epidemiology, etiology, management, and surgical outcomes of rotator cuff injuries in tennis players.

Recent Findings Rotator cuff injuries in tennis players are usually progressive overuse injuries ranging from partial-thickness articular- or bursal-sided tears to full-thickness tears. Most injuries are partial-thickness articular-sided tears, while full-thickness tears tend to occur in older-aged players. The serve is the most energy-demanding motion in the sport, and it accounts for 45 to 60% of all strokes performed in a tennis match, putting the shoulder at increased risk of overuse injury and rotator cuff tears. Studies have shown deficits in shoulder range of motion and scapular dyskinesia to occur even acutely after a tennis match. First-line treatment for rotator cuff injuries in any overhead athlete consists of conservative non-operative management with appropriate rest, anti-inflammatory drugs, followed by a specific rehabilitation program. Operative treatment is usually reserved for older-aged players and to those who fail to return to play after conservative measures. Surgical options include rotator cuff debridement with or without tendon repair, biceps tenodesis, and labral procedures. Unlike rotator cuff repairs in the general population, repairs in the elite tennis athlete have less than ideal rates of return to sport to the same level of performance.

Summary Rotator cuff injuries are a common cause of pain and dysfunction in tennis players and other overhead athletes. The etiology of rotator cuff tears in tennis players is multifactorial and usually results from microtrauma and internal impingement in the younger athlete leading to partial tearing and degenerative full-thickness tears in older players. Surgical treatment is pursued in athletes who are still symptomatic despite an extensive course of non-operative treatment as outcomes with regard to returning to sport to the same pre-injury level are modest at best. Debridement alone is usually preferred over rotator cuff repairs for partial tears in younger players due to potential over-constraining of the shoulder joint and decreased rates of return to sport after rotator cuff repairs.

Keywords Tennis · Shoulder · Rotator cuff · Tear · Impingement

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✉ Rami G. Alrabaa
ra2830@cumc.columbia.edu

Mario H. Lobao
mhl2155@cumc.columbia.edu

William N. Levine
wnl1@cumc.columbia.edu

[1] Department of Orthopedic Surgery, Columbia University Medical Center, 622 W 168th Street, PH-11, New York, NY 10032, USA

Introduction

Tennis players are susceptible to upper extremity injuries as chronic repetitive supraphysiologic forces are generated at the shoulder and elbow throughout a typical match. The shoulder is involved in all strokes in the sport and is particularly prone to injury during the serve and overhead. Similar to other overhead sports, upper extremity injuries are chronic and secondary to repetitive microtrauma and overuse, while lower extremity injuries in tennis athletes tend to be acute injuries [1, 2]. Multiple epidemiologic studies have noted that the most common injuries in tennis athletes are lower extremity injuries, closely followed by upper extremity injuries that typically involve the shoulder and elbow and lastly the trunk which commonly involves injuries to the lower back [3–5].

The overall prevalence of shoulder injuries among tennis players of all levels ranges from 4 to 17% [6, 7]. A recent study noted that apart from lower extremity injuries, shoulder injuries were the most common cause of professional tennis player departure from the sport [8]. The spectrum of shoulder pathology includes chronic rotator cuff inflammation (tendinosis), subacromial bursitis, partial-thickness rotator cuff tears, posterior capsule contracture, long head of biceps injuries, labral tears, scapular dyskinesia, and superior labrum anterior-to-posterior (SLAP) tears. This review will focus on rotator cuff tears, but it is important to keep in mind that tennis players often present with concomitant pathologies.

Rotator Cuff Injuries in Tennis Players

The overall injury incidence in tennis players across all competitive levels is estimated to be between 0.05 and 2.9 injuries per player per year and ranges from 0.04 to 3.0 injuries per player per 1000 h played [3]. In elite adolescent athletes, overall injury rates are higher ranging from 2 to 20 injuries per 1000 h played [6]. Overuse injuries to the shoulder have been shown to contribute to nearly 4 to 17% of all tennis injuries [1, 2, 4, 6, 7], but the true incidence of rotator cuff tears in tennis athletes remains unclear [9]. The prevalence of rotator cuff tears in overhead athletes may be underreported as many cuff tears are asymptomatic in athletes. Connor and colleagues [10] reported on imaging findings in completely asymptomatic shoulders of overhead athletes, and they found that 40% of dominant shoulders had MRI findings consistent with partial or full-thickness rotator cuff tears, while none of the non-dominant shoulders had any significant MRI findings. Another study imaged asymptomatic elite adolescent tennis players and found higher frequency of rotator cuff tendinosis on MRI of the dominant shoulder when compared with the non-dominant shoulder [11]. Rotator cuff injuries have also been extensively studied in baseball pitchers. Lesniak and colleagues [12] imaged the dominant shoulder in professional baseball pitchers who were completely asymptomatic and found that around half of the pitchers had partial or full-thickness rotator cuff tears. Moreover, the authors reported that pitchers with higher cumulative innings pitched had increased likelihood of rotator cuff tears on MRI even though they were asymptomatic. These findings suggest that rotator cuff injuries in overhead throwing athletes may be an adaptive response in order to accommodate the extremes in range of motion required for success in the sport [13•].

Rotator cuff pathology is common in the general elderly population in the form of degenerative tears to the anterosuperior rotator cuff with increasing prevalence with age [14]. Full-thickness tears are uncommon in the athlete under 35 years of age, but the rate increases in players older than 50 years of age [15]. As tennis players age, the primary cause of rotator cuff injury shifts from microtrauma due to posterosuperior internal impingement causing partial-thickness cuff tears to degenerative changes leading to full-thickness tears. Partial-thickness rotator cuff tears in the overhead athlete mostly affect the articular side of the tendon and are known as PASTA (partial articular-sided tendon avulsion) lesions. Bursal-sided tears are less common in the overhead athlete and are associated with subacromial impingement. Tears in athletes can also exhibit extension into an intratendinous or intralaminar portion of the tendon and are referred to as PAINT (partial-thickness articular surface intratendinous tears) lesions [13, 16]. Partial-thickness tears can be classified according to Ellman [17] in 3 grades based on tear depth (grade 1, < 3 mm deep or 25% of tendon width; grade 2, 3–6 mm or 50%; grade 4, > 6 mm or > 50%). This classification was revised by Snyder [18] to include location (bursal or articular) and tear severity.

Several mechanisms have been described to cause rotator cuff injuries in overhead athletes, including tensile overload, internal rotation deficit, internal impingement, scapular dyskinesia, and less commonly external impingement [19]. Repetitive and rapid eccentric contraction of the rotator cuff to decelerate the arm during the follow-through phase of the throw generates tensile forces that progressively overload the rotator cuff tendons leading to hypertrophy, microtrauma, and eventual failure of the tendon fibers [20]. These injuries have been well studied in professional baseball pitchers with literature reporting compressive loads as high as 860 N across the glenohumeral joint and humeral angular velocities up to 8000°/s during the throwing motion; the rotator cuff muscles act to offset these extreme forces to keep the humeral head stable and centered on the glenoid [21, 22]. During the tennis serve, there is major stress across the posterosuperior rotator cuff tendons from eccentric contraction to decelerate the arm from its maximum angular velocity [23].

Competitive tennis players and overhead athletes frequently develop excessive shoulder external rotation that seems to be an adaptation to the repetitive external rotation involved in the late cocking phase of the throwing motion. This leads to a corresponding glenohumeral internal rotation deficit (GIRD) as repeated microtrauma to the posterior capsule during the deceleration phase of the throw leads to scar formation and subsequent posterior capsule contracture. As shoulder internal rotation is essential in tennis especially for high velocity serving strokes and forehand ground strokes [24], GIRD alters the shoulder kinematics increasing the risk of shoulder injuries in tennis players and overhead athletes [25, 26].

During the late cocking phase of the serve, maximal external rotation and abduction of the shoulder cause abutment between the greater tuberosity of the humerus and the posterosuperior glenoid labrum. This abutment increases the contact pressure in the articular surface of the posterosuperior rotator cuff leading to a characteristic bipolar injury to the posterosuperior labrum and the articular aspect of the posterior supraspinatus and anterior infraspinatus tendons (Fig. 1). Walch and colleagues [27] dubbed this "internal impingement" and described arthroscopic findings of fraying of the posterosuperior labrum and partial-thickness tearing of the undersurface of the rotator cuff. GIRD and internal impingement seem to be intimately associated with one another. Burkhart and colleagues [20] proposed that the posterior capsular contracture may be the primary structural alteration for the development of internal impingement. Repeated eccentric contraction of the posterosuperior cuff leads to hypertrophy and subsequent stiffness of the posterior structures limiting anterior translation of the humeral head in abduction and external rotation ultimately leading to internal impingement.

Altered scapular mechanics also play a role in cuff injuries. In the late cocking and early acceleration phases of throwing when the humerus is maximally abducted and externally rotated, the scapula undergoes upward rotation to help maintain glenohumeral articular congruency [28]. Imbalance or weakness of the periscapular or posterior cuff muscles may disrupt the dynamic relationship of the scapula and is referred to as scapular dyskinesia. Burkhart and colleagues [20] have described the SICK (scapular malposition, inferior medial border prominence, coracoid pain and malposition, and dyskinesis of scapular movement) scapula syndrome which comprises a characteristic set of features and findings associated with altered scapular kinematics in overhead athletes. Disruption of the scapulohumeral rhythm may also lead to external impingement of the cuff along the coracoacromial arch and result in rotator cuff injuries [19]. The ability to maintain scapular upward rotation during serving seems to be important to prevent chronic injury risk in tennis players. Rich and colleagues [29•] demonstrated that fatigued tennis players had decreased scapular upward rotation during serving, suggesting that heavy serving activity during tournaments acutely leads to abnormal scapular movement patterns that can play a role in long-term rotator cuff injuries. The authors recommend close monitoring of scapular upward rotation in tennis players returning to play after shoulder injuries.

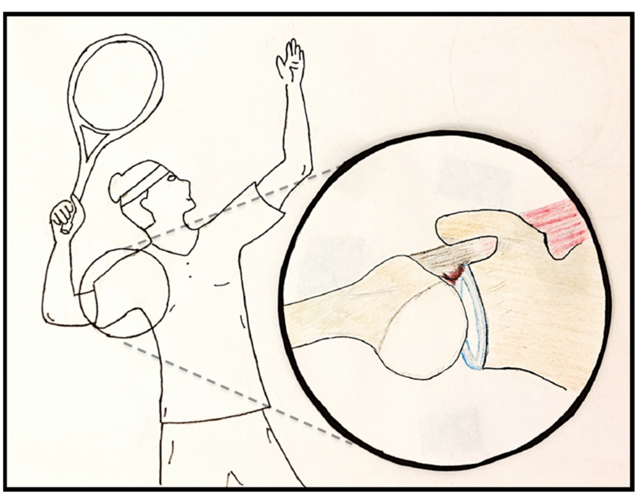


Fig. 1 With repetitive abduction and external rotation, the overhead athlete can develop internal impingement leading to partial-thickness tearing of the posterosuperior rotator cuff and labrum

External or subacromial impingement as described by Neer [30] is a common cause of rotator cuff disease in the older population as the cuff tendons impinge in the coracoacromial arch. Although less common in overhead athletes, external impingement can be a cause of rotator cuff disease, bursitis, and cuff dysfunction, as well as subscapularis tears due to repetitive impingement of the lesser tubercle against the coracoid during the follow-through phase of the forehand ground stroke. Although several injury mechanisms exist, one mechanism alone may not be solely involved in the injury process as several mechanisms act in a cascade of events overtime leading to rotator cuff injuries in overhead athletes.

Tennis Specific Considerations

The serve is the predominant stroke in tennis accounting for 45 to 60% of all strokes in a service game [31, 32]. As most tournaments are composed of 3-set matches and a player averages 120 serves and 210 ground strokes per match [33•], a high-level tennis player can accumulate around 5400 serves during a competitive season (45 matches per year) without accounting for ground strokes. In contrast, a Major League Baseball pitcher averages approximately 100 pitches per game every 4 days and an overall count of 2655 pitches throughout the season.

Tennis players must use the kinetic chain efficiently to generate power shots. Forces generated at the feet, legs, knees, and thighs travel through the core (abdomen and trunk) and are transmitted to the shoulder, elbow, wrist, hand, and ultimately the racket [34]. The shoulder plays a crucial role in this kinetic chain by transmitting forces while producing a wide range of motion. This is particularly evident in the serve, which has been documented to be the most strenuous stroke on the upper extremity. An explosive contraction of the internal rotator muscles with the shoulder in abduction and external rotation produces an angular velocity of 2420°/s at the acceleration phase of the serve [31]. Depending on the athlete's strength, endurance, flexibility, and skill level, improper technique or fatigue disrupts the kinetic chain leading to inefficient energy transfer and overloading across subsequent joints which can lead to injuries [24]. It has been shown that inappropriate knee flexion during a serve significantly increases the mechanical loads to the upper extremity [35]. Elite and experienced players seem to have more efficient energy transfers in their kinetic chain compared with novice or recreational players who tend to overload the shoulder and elbow joints due to improper technique leading to higher injury risk [36, 37]. Energy transfer between segments (kinetic chain) is a critical concept related to sports injury. An energy flow study comparing injured and uninjured tennis players showed that with higher quality of energy transfer from the trunk to the hand and racket led to increased ball velocity and decreased upper limb joint kinetics [38]. Injured players had a lower overall quality of energy flow through the upper extremity, lower ball velocity, and higher energy absorbed by the shoulder and elbow which likely predisposed them to overuse injuries.

Three main serve types have been described including flat, top-spin or kick, and slice. The top-spin serve is commonly taught to junior tennis players or shorter athletes so that the ball clears the net while still landing in the service box; the top-spin serve is also commonly used as the second serve because of its reliability. Motion analysis and biomechanical studies have shown that the top-spin serve results in the greatest force, while the slice serve had the lowest overall forces and torques generated on the shoulder [39]. Therefore, the top-spin serve should be used judiciously in younger players due to the potential risk of shoulder injuries. This biomechanical data is also relevant to rehabilitation of shoulder injuries, injury prevention, and return-to-play protocols; players recovering from shoulder injuries or surgery should start with slice serves as they generate the least forces and progress top-spin or kick serve at later stages of rehabilitation.

As described earlier, GIRD and internal impingement are intimately related and contribute to shoulder injuries and rotator cuff tears in tennis players [40]. A recent study demonstrated significant decrease in internal rotation of the dominant shoulder in tennis players after 3 h of play [41•]. These acute changes in shoulder range of motion influence the serve kinetic chain predisposing to shoulder injury during long matches. Tennis players should be encouraged to stretch after matches and allow for adequate time to rest in between matches to restore baseline shoulder range of motion to avoid injury and maintain performance. Another study by Rich and colleagues [29•] examined healthy tennis players without any shoulder injuries and had them undergo a tennis serving protocol in order to induce fatigue. The study reported that scapular upward rotation was significantly diminished after fatigue but returned to baseline within 1 day. Similarly, the authors draw attention to the decreased range of motion and altered kinematics of the shoulder after prolonged tennis and caution any athlete to return to competition within a day after heavy serving.

Tennis rackets have transformed from heavy wooden models to larger yet lighter and stiffer graphite composite models [2]. Modern rackets and strings allow for faster balls and increased spin at the expense of higher torques transmitted to the shoulder and elbow which may account for upper extremity overuse injuries [32]. In terms of play surface, hard courts result in faster ball speeds, which theoretically subject the upper extremity to higher forces; however, there is no evidence showing higher injury rates due to a specific playing surface [2, 42].

Clinical Evaluation

History

Most overhead athletes and tennis players with rotator cuff injuries present with progressive dull shoulder pain, early fatigue, and decreased performance [19]. Pain location is vague and can radiate laterally to the deltoid. Anterior shoulder pain may indicate concomitant labral tear, proximal biceps pathology, or anterior instability, while posterior pain suggests posterior labral pathology or instability. The onset of symptoms, any history of shoulder instability, and other traumatic events should be documented. Symptoms are commonly exacerbated after overhead activities and especially after the serve.

The overhead athlete may have specific complaints related to performance, like early fatigue, decreased strength, decreased throwing or serving velocity, decreased accuracy, or mechanical symptoms. Information about the athlete's training regimen, compliance to rest days, and frequency of competition and practice sections is important to assess for overuse. Possible contributing factors include any recent changes in strokes or equipment that may suggest improper or less ideal technique. Finally, the athlete should be screened for other sources of pain including the back, core, and lower extremities as restoring proper technique is the main focus in rehabilitation if a technical deficiency is identified [2, 35].

Physical Exam

Detailed physical examination of the shoulder is performed beginning with inspection, palpation, range of motion evaluation, strength assessment, and progressing to provocative maneuvers. Inspection of bilateral scapulae from behind the patient with the entire torso exposed is paramount to detect differences in scapular motion between sides that may indicate SICK scapula. Asymmetric position, protraction, or a deficit in upward rotation of the scapula with range of motion may indicate scapular dyskinesia. Selective atrophy of the supraspinatus and/or infraspinatus when compared with the contralateral shoulder is a sign of suprascapular nerve compression, which can clinically present with weakness and pain similar to a rotator cuff tear.

Palpation proceeds in a systematic fashion assessing for tenderness of the sternoclavicular joint, acromioclavicular joint, proximal biceps tendons, and along the supraspinatus and infraspinatus fossa. Range of motion is compared with the contralateral shoulder in forward elevation in the scapular plane, external and internal rotation with the arm at the side, abduction, and external and internal rotation in abduction. GIRD can be evident in the dominant shoulder in tennis players with increased external rotation in abduction and a corresponding decrease in internal rotation. Although there is increased external rotation and decreased internal rotation in the dominant shoulder compared with the non-dominant arm, the total arc of rotation of both shoulders should be equivalent [25]. Rotator cuff strength is assessed and compared with the contralateral shoulder. Subtle differences may not be detected as other more powerful muscles contribute to shoulder motion and the cuff muscles are rarely testing in isolation. While rotator cuff tears in elderly patients may result in significant objective weakness and lag signs, that is unusual in athletes and younger players even in the presence of full-thickness rotator cuff tears because other powerful muscles like the deltoid, pectoralis major, and latissimus dorsi compensate for the rotator cuff deficiencies.

Provocative maneuvers then focus on different structures about the shoulder. Classic impingement (external or subacromial impingement) is assessed with the Neer and Hawkins tests. Since concomitant pathology is common in overhead athletes, maneuvers to identify labral pathology and instability are always performed. Athletes with anterior-inferior instability will demonstrate apprehension with abduction and external rotation and have positive relocation and anterior release signs. Superior labral pathology including SLAP tears can be assessed with the active compression and posterior stress tests. Clinically diagnosing SLAP tears is difficult as there is no single test with optimal specificity. Despite the availability of a specific exam maneuver, one study reported that labral lesions were best identified by a combination of the modified dynamic labral shear and active compression maneuvers [43]. Posterior labral pathology is examined with the Jerk and Kim tests. Closely associated proximal biceps tendon pathology is assessed with the Speed and Yergason maneuvers. With the emphasis on the detection of internal impingement in overhead athletes, several examination maneuvers have been developed including the modified relocation test and the internal rotation resistance test [44, 45].

Imaging

Accurate diagnosis requires correlating a thorough history and physical exam with imaging findings. Plain radiographs are obtained in all patients and include an anteroposterior view of the scapula (Grashey), axillary, and scapular Y views. The morphology of the acromion is assessed on the scapular Y view and classified as flat, curved, or hooked. Hooked acromions are more often associated with rotator cuff tears [46, 47]. Other radiographic findings that suggest rotator cuff tears include sclerosis or cysts in the greater tuberosity [9]. Ultrasound imaging to assess rotator cuff integrity has the benefits of being low-cost, easy patient tolerance, and dynamic evaluation of the tendons. However, ultrasound remains operator- and facility-dependent [48]. A meta-analysis on the effectiveness of ultrasound for the diagnosis of rotator cuff injuries showed a sensitivity of 84% and specificity of 89% for partial-thickness tears and a sensitivity of 96% and specificity of 93% for full-thickness tears [49].

The gold standard to diagnose rotator cuff tears is magnetic resonance imaging (MRI). Advantages include the ability to evaluate concomitant pathology including the biceps tendon, labrum, capsule and cartilage in addition to less operator-dependency, and high accuracy. A meta-analysis showed a pooled sensitivity and specificity of 80% and 95%, respectively, for diagnosing partial-thickness cuff tears on MRI with higher sensitivity and specificity values (0.91 and 0.97) for full-thickness tears [50]. Higher-field strength MRIs and the availability of musculoskeletal radiologists led to improved accuracy. Differentiating between tendinosis and partial-thickness tears can be difficult using conventional MRIs. Enhanced diagnostic accuracy can be achieved for diagnosing partial-thickness cuff tears and labral pathology with the use of MR arthrography (MRA) (Fig. 2), placing the arm in the throwing position in abduction and external rotation (ABER view), and higher-field (3 T) strength magnets [51]. One study of arthroscopically confirmed partial-thickness cuff tears with a horizontal component showed that only 21% of the lesions were detected on standard coronal oblique MRI images, while 100% of the lesions were identified on ABER views [52].

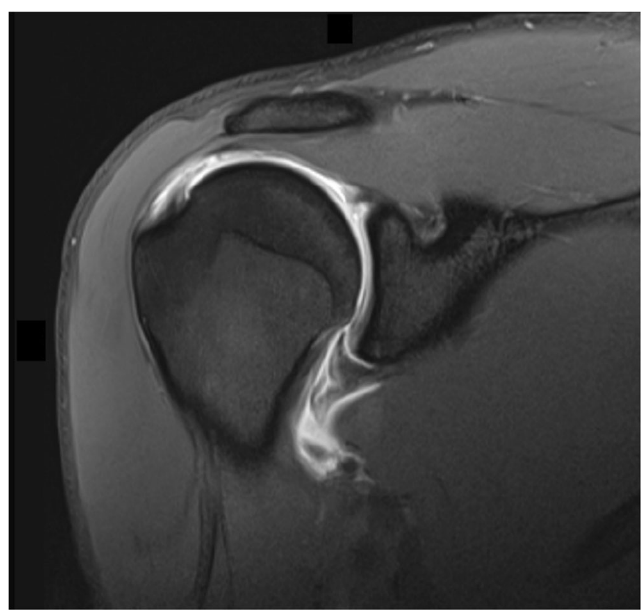


Fig. 2 MR arthrogram of the dominant right shoulder of a 20-year-old male overhead athlete showing partial articular-sided tearing of the supraspinatus. The tear appears to involve approximately 75% of the tendon thickness with an intact bursal surface. This patient was treated with repair of the partial tear with an arthroscopic transtendon repair technique shown in Figs. 3, 4, and 5

The clinician must use caution when interpreting MRI studies. As previously mentioned, several studies have found abnormalities of the rotator cuff on imaging in completely asymptomatic overhead athletes and tennis players [10–12]. Moreover, the timing of the MRI after injury or onset of symptoms is important to consider as there can be signal abnormalities found in overhead athletes after competition, which can take up to a week to normalize on imaging [53, 54].

Management

Treatment of rotator cuff injuries in tennis players depends on several patient- and injury-specific factors including onset of injury, thickness of the cuff tear, extent of impairment, presence of concomitant injuries, timing within the season or off-season (in an elite or professional athlete), and response to non-operative treatment.

Non-operative

First-line non-operative treatment of rotator cuff injuries in tennis players includes rest from the sport and overhead activities, physical therapy, and a rehabilitation program. Duration of non-operative treatment varies on severity of symptoms, pathology, and the individual athlete. Most treatment plans involve at least 3 months as a reasonable period for a comprehensive rehabilitation program [9, 54, 55]. Non-operative treatment should be exhausted prior to consideration of surgery for the elite tennis player as the results of surgical intervention are unpredictable in terms of resolution of symptoms and return to previous level of sport.

During the resting phase of treatment, NSAIDs may be used to decrease inflammation and pain to assist in the rehabilitation phase. Selected athletes may also benefit from a corticosteroid injection to decrease inflammation and facilitate therapy especially if there are signs of subacromial impingement or bursal-sided tearing [13•]. Articular injection is an option for articular-sided rotator cuff injuries. Corticosteroid injections should be used sparingly in the young athlete due to risks of tendon weakening and rupture [56, 57]. In a meta-analysis, Boudreault and colleagues [58] reported that oral NSAIDs and corticosteroid injections may have similar short-term efficacy in terms of pain reduction and functional improvement in the treatment of rotator cuff tendinopathy. However, this study was not limited to athletes. Other studies have shown mixed results with regard to the efficacy of subacromial steroid injections for rotator cuff pathology in the general population with some studies demonstrating reduction in pain and improved function, while others reported no difference when compared with NSAIDs or placebo [59–63]. There is limited evidence-based literature on the use of corticosteroid shoulder injections in elite athletes. A few case series of collegiate athletes show at least temporary relief of symptoms with subacromial steroid injections for rotator cuff pathology, but inconclusive results at mid- and long-term [64, 65]. The use of platelet-rich plasma (PRP) has gained popularity for the treatment of various orthopedic conditions. Although there is no literature on the use of PRP specifically in rotator cuff injuries in athletes, general population studies show no difference in outcomes between patients who received PRP and controls for the treatment of rotator cuff tendinopathy [66, 67]. Furthermore, significant variability in the PRP attainment methods across different systems makes it challenging to draw definitive conclusions [68, 69].

Treatment in the tennis player should evaluate the athlete's serve and stroke mechanics. As discussed previously, the entire kinetic chain must be assessed, including lower limbs and core because improper technique at any link of the chain may disrupt the energy transfer downstream in the chain manifesting in upper extremity overuse injuries. Therefore, strength training of the core, lower, and upper extremities as well as proper serve and stroke mechanics must be emphasized during the rehabilitation process to minimize recurrent or new site injuries. Physical therapy begins with exercises focused on maximizing range of motion followed by strengthening of the rotator cuff and periscapular muscles. GIRD should be addressed with sleeper stretches of the posterior capsule [20]. Scapular dyskinesia and SICK scapula require progressive stretching program and integrating scapular strengthening exercises by having the athlete retract the scapula to its normal anatomic position [19]. Once shoulder range of motion improves and rotator cuff strengthening is enhanced, the last phase of rehabilitation in non-operative treatment involves a gradual return to sport specific exercises and training. Wilk and colleagues [70•] reported on an evidence-based comprehensive 4-phase rehabilitation program for non-operative treatment of shoulder issues including rotator cuff tears in the overhead athlete. Another review by Cools and colleagues [71] outlines the rehabilitation guidelines for internal impingement specifically in the tennis player.

Operative

When an athlete is unable to return to tennis despite extensive non-operative treatment, surgery can be pursued. It is important, however, to have a frank discussion with the patient, trainers, and managers of elite athletes regarding the unpredictability of surgical outcomes in terms of return to sport at a high level. Surgical approaches have evolved from open to mini-open to arthroscopic with limited literature supporting one approach over another, but arthroscopic surgery is most commonly preferred and performed in athletes [13, 55]. Surgical treatment includes debridement alone, partial or full-thickness rotator cuff repair, and treatment of concomitant

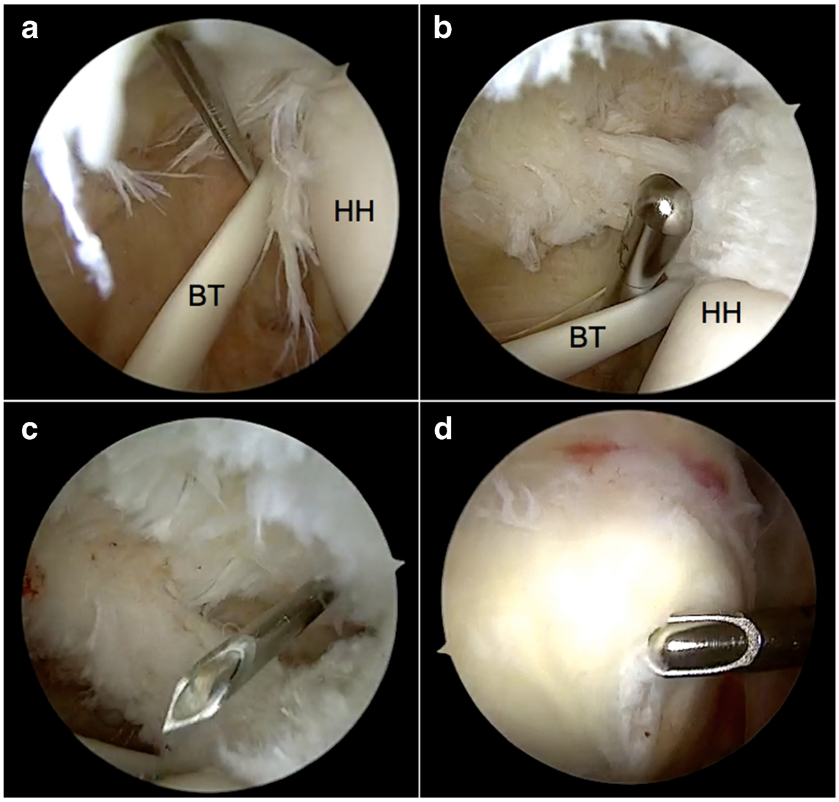


Fig. 3 Transtendon repair technique of the partial articular cuff tear shown on imaging in Fig. 2 of the patient's right shoulder. Patient is placed in the lateral decubitus position. (**a**) Intra-articular view from a standard posterior portal of the articular surface of the supraspinatus shows partial-thickness tearing and fraying. (**b**) The undersurface of the cuff is debrided with a motorized shaver to stable margins. (**c**) A spinal needle can be placed percutaneously through the tear under visualization, and a monofilament suture can be passed through the eyelet of the needle in order to mark the tear from within the joint in order to evaluate its corresponding bursal surface from the subacromial space. (**d**) The arthroscope and shaver are introduced into the subacromial space to complete a bursectomy and evaluate the bursal side of the cuff. In this case, the bursal side is intact; however, there is significant tearing of the articular side estimated to be at least 75% of the tendon thickness, so the decision was made to proceed with transtendon repair (BT, biceps tendon; HH, humeral head)

pathology found at the time of arthroscopy (including labral or SLAP repair, biceps tenodesis or tenotomy, or acromioplasty).

Ultimately, patient age, preoperative imaging, size and retraction of the tear, tissue quality, and surgeon experience or preference play a role in determining the surgical plan. Surgical treatment begins with debridement to assess tear depth and extent. Irregular unhealthy tendon edges and flaps are debrided. Partial-thickness articular-sided cuff tears are debrided from within the joint to a stable margin. Using a spinal needle, a monofilament suture is percutaneously placed to mark the partial-thickness cuff injury. The suture is then identified in the subacromial space, and the bursal cuff integrity is examined.

Options for management include debridement alone, bioinductive scaffold placement on the bursal cuff, transtendinous repair, or conversion to full-thickness tear and repair. Historically, recommendations in the general population report that tears under 50% of the tendon thickness can be debrided alone, whereas tears involving more than 50% of the tendon should be repaired. This "cutoff" has been propagated in the literature, and there is some biomechanical evidence that suggests significantly increased strain with partial articular cuff tears exceeding 50% of the tendon thickness [72]. However, there is no technique to accurately determine the thickness of the tear, and one study has shown that there is poor interobserver reliability when estimating the extent of partial-thickness tears [73]. While the 50% threshold has historically been used for tendon repair, more recent literature suggests repair only of more advanced partial-thickness tears exceeding 75% in the young overhead athletic population [9, 55]. This is largely due to unpredictable outcomes of cuff repair in the athlete and the risk of over-tensioning the cuff leading to a non-anatomic repair and possibly functional deficits in the sport.

Partial-thickness articular cuff tears can be repaired with a transtendinous approach (Figs. 3, 4, and 5) or by completing the tear creating a full-thickness defect and then proceeding with repair back to the footprint. This is controversial in tennis players due the concern of over-tensioning, loss of motion, and inability to return to tennis. The transtendon repair technique advances the articular fibers to the medial footprint while maintaining the lateral fibers intact. It is essential to plan the appropriate placement of the anchors in order to achieve an

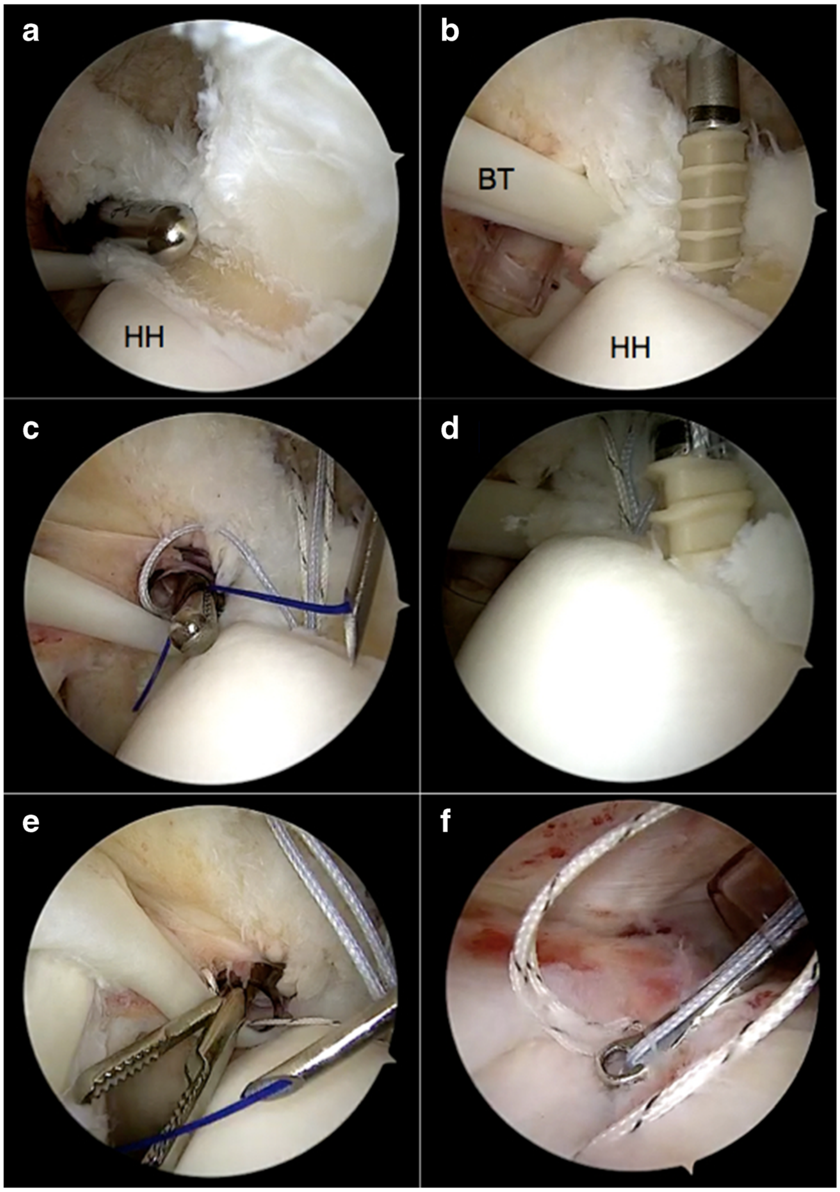


Fig. 4 Transtendon repair technique of the partial articular cuff tear shown on imaging in Fig. 2 of the patient's right shoulder. (**a**) View from a standard posterior portal. The medial footprint is debrided down to bone with a motorized shared just lateral to the humeral head articular surface. (**b**) Decision was made to place 2 medial anchors for this repair, so the first anterior anchor is placed percutaneously, and then sutures are passed through the tendon. First, a suture limb is retrieved from the anterior cannula. Then a spinal needle is percutaneously placed through tendon in anticipation of where the suture must be passed. (**c**) A monofilament blue suture which is to be used as a shuttling suture is passed through the eyelet of the spinal needle and is retrieved out the anterior portal. The blue braided suture from the suture anchor is then looped around the shuttling suture outside the body from the anterior cannula. The monofilament shuttling suture is then retrieved from its percutaneous entry site (where it was placed through the spinal needle), therefore passing the blue braided suture through the tendon at the desired location. (**d**) The second posterior suture anchor is then placed percutaneously. The location of this posterior anchor was crucial in this case as it was used to reduce the posterior cable tissue that was detached. (**e**) Again, sutures from the second anchor are passed through the tendon in the same manner as described. Once all sutures are passed through the tendon, they are tied in the subacromial space. (**f**) The arthroscope is introduced into the subacromial space and a lateral cannula is established. The corresponding suture limbs are tied together using a knot pusher to reduce the tear (BT, biceps tendon; HH, humeral head)

anatomic repair; any detached rotator cable tissue should be restored back to the footprint as significant compromise of the cable tissue can alter glenohumeral kinematics [74•].

Partial articular-sided cuff tears are completed into full tears and repaired if it is determined that the majority of the tendon thickness is involved (over 75%), if the quality of the intact lateral fibers are poor, or if there is substantial bursal-sided involvement. Full-thickness cuff tears can then be repaired as they are in the general population using either single- or double-row techniques. Double-row and

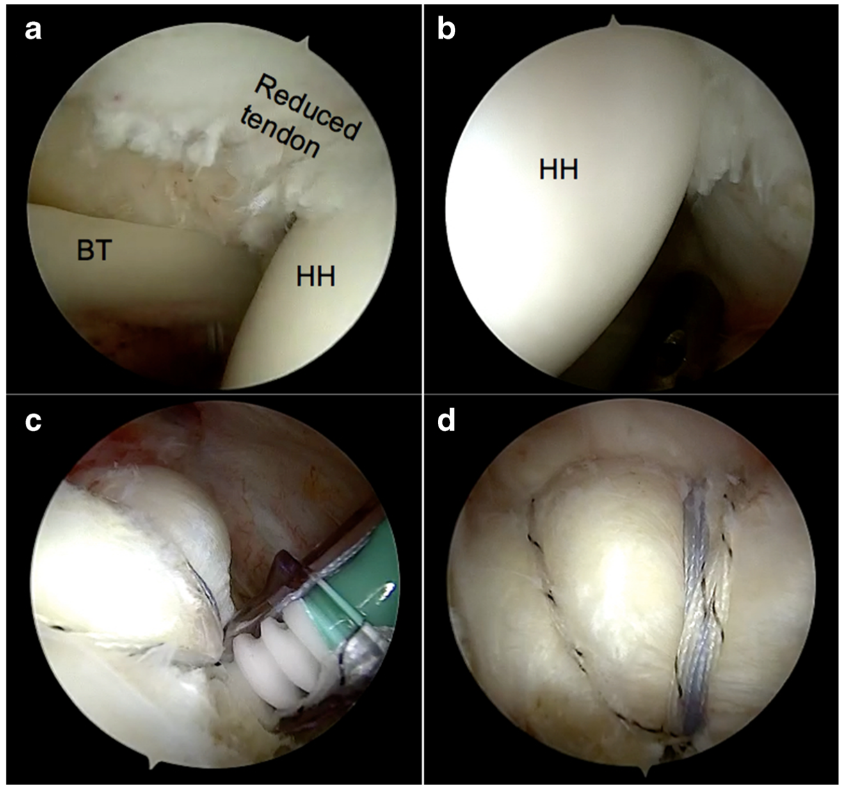


Fig. 5 Transtendon repair technique of the partial articular cuff tear shown on imaging in Fig. 2 of the patient's right shoulder. (**a**) Intra-articular view from the posterior portal showing the anterior aspect of the tendon reduced to the medial footprint. (**b**) Intra-articular view from the anterior portal showing the posterior aspect of the tendon reduced. At this point, the decision was made for placement of a lateral row anchor incorporating all the suture limbs that were tied in order to provide compression. (**c**) Subacromial view showing placement of the lateral row anchor incorporating all the suture limbs that were tied. (**d**) View from the lateral subacromial portal showing the final repair construct (BT, biceps tendon; HH, humeral head)

transosseous equivalent repairs have been shown to have increased strength, resistance to cyclic loading, and improved footprint coverage [75, 76].

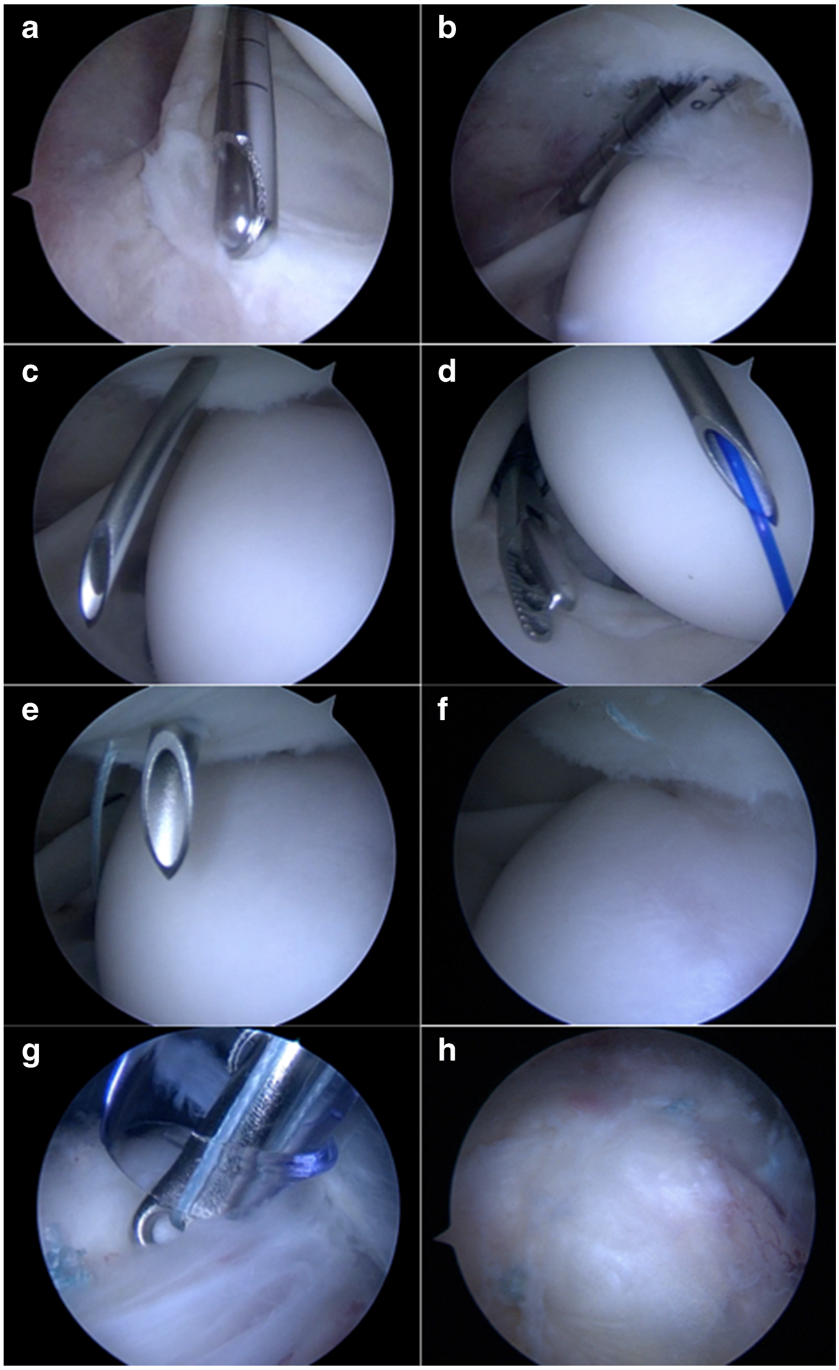
Intralaminar tears can occur specifically in overhead athletes and are termed partial-thickness articular surface intratendinous (PAINT) lesions. These tears can be repaired with side-to-side sutures without anchoring the repair back to the bony footprint in order to avoid excess tensioning of the cuff (Fig. 6) [13, 16, 77]. Over-tensioning the repair by passing sutures to medial on the cuff in a suture anchor repair or not recreating an anatomic footprint during repair can lead to tightening of the shoulder which will compromise the kinematics of the tennis player and may lead to functional deficits in the sport.

Outcomes

A few studies investigate the outcomes of rotator cuff repair or debridement in tennis players specifically. Sonnery-Cottet and colleagues [15] retrospectively evaluated 51 tennis players with partial or full-thickness tears. Thirty-two patients were recreational tennis players, while 19 were elite competitive tennis players. The authors reported that full-thickness tears were more common in the older player, while partial-thickness tears were more common in the younger player. In their cohort, 42 patients underwent cuff repair, while 9 patients had debridement alone. Seventy-eight percent (40 of 51) of patients were able to return to tennis at an average of 10 months after surgery; the authors reported no difference in return to tennis between the repair or debridement cohorts. Bigliani and colleagues [78] also retrospectively reviewed their series of rotator cuff repairs in tennis players. They reviewed 23 tennis players with an average age of 58 years who underwent repair of cuff tears at an average 39-month follow-up. Overall, 22 of 23 patients returned to tennis with 19 returning to the same level, while 3 returned at a lower level. Only 1 patient was unable to return to tennis. While these 2 studies demonstrated positive outcomes for return to tennis, more recent studies in younger athletes show more unpredictable results. A recent small case series of 8 professional female tennis players who underwent shoulder surgery on their dominant arm (5 of which were due to rotator cuff injuries) reported that 7 of 8 players were able to return to professional play; however, only 2 of 8 were able to return to the same level of play and ranking postoperatively [79•].

Tibone and colleagues [80] also retrospectively reviewed their series of 45 athletes with an average age of 45 years (with the majority of patients having partial-thickness tears) and found that only 56% of athletes were able to return to sport at their pre-injury level. Of the athletes who required maximal arm abduction and external rotation for their sport, only 41% (12 of 29) were able to return to play.

A recent meta-analysis [81•] reviewed 25 studies with 859 patients and assessed return to sport after surgical treatment of rotator cuff injury. The most common sport was baseball



followed by tennis. The authors found that the overall rate of return to sport was 84.7% with 65.9% of patients returning to the same level of play. However, when isolating for professional or competitive athletes, only 49.9% of these athletes were able to return to an equivalent level of play. Altintas and colleagues [82•] showed in a systematic review of 15 studies (486 patients) that 70.2% of athletes were able to return to pre-injury level of play after arthroscopic rotator cuff repair. However, only 61.5% of elite/competitive athletes did so, and only 38% of overhead athletes returned to the same level of play. These findings are supported by another study that showed the majority (88%) of recreational athletes were able to return to some sport activity after rotator cuff repair with a decreased percentage (68%) returning to the same sport; but competitive athletes did so at a much lower rate [83]. Another study retrospectively reviewed 32 adolescent athletes (average age 16) who underwent arthroscopic rotator cuff repair for mostly partial tears. The authors reported that the majority of overhead athletes (93%) were able to return to sport; however, more than half (57%) were forced to play a different position in the sport [84•]. Several other studies have shown less than ideal outcomes for overhead athletes treated operatively for rotator cuff

◀ **Fig. 6** The arthroscopic repair of a laminated rotator cuff tear referred to as a PAINT (partial-thickness articular surface intratendinous tear) lesion in a side-to-side fashion to repair the laminated portions without anchoring back to the footprint in order to avoid over-tensioning of the cuff and potential deficits in abduction and external rotation. Patient is a 22-year-old right-hand-dominant male and high-level overhead athlete with right shoulder pain. MRA confirmed partial-thickness articular-sided cuff tearing at the posterior supraspinatus and anterior infraspinatus junction along with posterosuperior labral fraying. These findings were consistent with internal impingement in this elite overhead athlete. Patient was placed in the lateral decubitus position, and diagnostic arthroscopic began from a standard posterior portal. (**a**) View from the posterior portal shows posterosuperior labral fraying that was debrided. (**b**) The motorized shaver is placed in between the laminated flaps to stimulate healing. After debridement of the tear, the arthroscope is introduced into the subacromial space to assess the bursal aspect of the cuff which was intact in this case. (**c**) A spinal needle is placed percutaneously to capture both layers of the laminated tear. A monofilament suture (blue PDS suture in this case) is threaded through the eyelet of the spinal needle to serve as a shuttling suture. (**d**) The shuttling suture is retrieved from the anterior portal. Outside the anterior portal, a braided high tensile strength suture is wrapped around the shuttling suture, and the shuttling suture is retrieved from its percutaneous entry site in order to pass the suture through the cuff tissue. (**e**) A spinal needle is then percutaneously introduced to pass the cuff posterior to suture that was already passed, and a shuttling suture is again passed through the spinal needle and retrieved from the anterior portal, and the suture limb from the anterior portal that was already passed through the cuff is shuttled through. (**f**) These steps create a suture in horizontal mattress configuration as shown. This process is repeated 3 times in order to create 3 horizontal mattress sutures to repair the laminated flaps. (**g**) After all sutures are passed, the arthroscope is introduced into the subacromial space, and the corresponding suture limbs are tied to each other through a lateral subacromial cannula. (**h**) Subacromial view of the final repair construct of the PAINT lesion without restoration to the footprint to avoid compromise of abduction and external rotation

tears in terms of return to play to the same level. At the professional level, full-thickness rotator cuff tears may be career-ending injuries. Mazoue and Andrews [85] reviewed a cohort of 16 professional baseball players who underwent repair for full-thickness cuff tears and noted that only 1 pitcher and 1 position player were able to return to professional play following surgery on their dominant arm.

In summary, there appears to be a distinction between the older, recreational tennis player with a full-thickness rotator cuff tear and the younger, higher level player with a partial-thickness tear. The outcomes of surgical treatment in terms of return to sport is favorable for the older recreational athlete, while several studies in the sports literature show less than ideal return to sport to the same level of play in the younger more competitive athlete.

Conclusions

Tennis players and other overhead athletes are predisposed to overuse injuries of the shoulder, including rotator cuff tears. MRI remains the gold standard for imaging of rotator cuff pathology and other concomitant injuries about the shoulder. Primary treatment of rotator cuff tears is non-operative with a period of rest followed by progressive rehabilitation. Proper technique is emphasized during the rehabilitation process as well as strengthening of the overall kinetic chain including the trunk and lower extremities.

Adequate rest between tennis matches can help minimize injury as studies have shown alterations in shoulder range of motion and scapular kinematics after prolonged play that self-resolve with rest. Rotator cuff injuries in the tennis player are most commonly partial articular-sided tears. Full-thickness tears occur in the older tennis player and are likely due to degenerative changes. If non-operative treatment fails, surgical treatment can be pursued, but results are modest at best for return to sport to pre-injury level of play. Full-thickness tears are treated as they are in the general population with repair back to the footprint with suture anchors; however, it must be recognized that full repair may be difficult for the tennis player to return to pre-surgical form. Partial-thickness tears can be treated with debridement alone or with partial repair; the tear can also be completed into a full-thickness tear and then subsequently repaired to the footprint. In the general population, partial-thickness articular-sided tears are generally repaired if the tear involves more than half of the tendon thickness. A higher threshold exists for repair of cuff tears in younger high-level athletes as several studies show less than ideal outcomes in terms of return to sport and return to the same level of play as compared with the older recreational tennis player. These decreased outcomes may be related to over-constraint of the athlete's shoulder after a cuff repair as several studies have shown imaging consistent with partial-thickness cuff tears in asymptomatic overhead athletes suggesting that the "pathology" may be an adaptive response to allow for extremes of range of motion in abduction and external rotation. Finally, newer technology including use of a bioinductive scaffold to enhance healing may be an option to consider in the future, but further research is necessary before it can be widely recommended.

Compliance with Ethical Standards

Conflict of Interest Rami G. Alrabaa and Mario H. Lobao declare that they have no conflict of interest.

William N. Levine reports American Shoulder and Elbow Surgeons: Board or committee member. Journal of the American Academy of Orthopedic Surgeons: Editorial or governing board. Zimmer: Unpaid consultant.

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.

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