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SPORTS INJURIES AND REHABILITATION: GETTING ATHLETES BACK TO PLAY (R GALLO, SECTION EDITOR)

Scapular Dyskinesis and the Kinetic Chain: Recognizing Dysfunction and Treating Injury in the Tennis Athlete

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Abstract

Purpose of Review This article aims to provide a comprehensive understanding of the evaluation, diagnosis, and management of scapular dyskinesis and its impact on the kinetic chain in tennis athletes.

Recent Findings Optimal glenohumeral biomechanics are intimately associated with proper scapular motion and function. The tennis serve requires the scapula to act as a force transducer in the kinetic chain to convert potential energy generated in the lower extremities to kinetic energy in the upper extremity. Any aberration within this complex kinetic chain will result in force uncoupling and increases the potential for injury through compensatory mechanisms. Specifically, scapular dyskinesis has been associated with an increased risk of shoulder pain of up to 43% in overhead athletes. These pathologies include rotator cuff disease, subacromial and posterior impingement, labral injuries, and SLAP tears. Although the direct causality of these injuries remains controversial, multiple kinematic studies have demonstrated altered scapular positioning increasing the predilection for soft tissue pathology.

Summary The diagnosis of scapular dyskinesis is predicated upon a thorough history, physical examination, and observational analysis of key nodes in the kinetic chain during tennis activity. Conservative management remains the mainstay of treatment and consists of a graduated physical therapy regimen. Although shoulder pain in the overhead athletes is often multifactorial, early recognition and treatment of scapular dyskinesis generally carry a favorable prognosis and result in improved patient outcomes.

Keywords Scapular dyskinesis · Tennis kinetic chain · Shoulder pain in the tennis athlete · Tennis nodes

Introduction

The glenohumeral joint allows for the greatest range of motion in the human body and is pivotal in force transmission for overhead athletes. Tennis, specifically the serving motion, requires a repetitive overhead abduction-external rotation moment which places an unnatural and highly dynamic load on the shoulder, often exceeding the physiologic limits of the joint [1]. Therefore, optimal energy transfer from the trunk to the distal aspect of the upper extremity requires a delicate and reproducible balance between shoulder mobility and stability. Any aberration within this complex kinetic chain leaves the shoulder highly susceptible to injury. Lehman reported a 24% prevalence of shoulder pain in high-level adolescent tennis players with an increase up to 50% in middle-aged participants [2]. Other studies demonstrated shoulder injuries in tennis players at all levels ranging from 4 to 17% [3–5].

The scapula is intimately linked with glenohumeral biomechanics, and its dysfunction has been associated with an increased risk of shoulder pain in up to 43% of overhead athletes [6•]. Scapular dyskinesis, aptly named for the pathologic positioning and motion of the scapula, has been associated with common pathologies such as rotator cuff tears, labral tears, and shoulder impingement [7–11]. Clarsen further demonstrated an increased risk of shoulder pain in elite handball players with obvious scapular dyskinesis [12]. Additionally, Lopes showed that patients with symptoms of subacromial

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impingement and scapular dyskinesis had reduced scapular external rotation and greater loss of shoulder function as compared with those without dyskinesis [13]. However, there have been multiple studies that have failed to find any association between scapular dyskinesis and shoulder pain in baseball players [14•, 15]. Despite the current debate regarding causality, current literature supports scapular dyskinesis as an indirect contributor to shoulder pain in the overhead athlete [6•]. Therefore, the purpose of this article is to provide a comprehensive understanding of the evaluation and treatment of scapular dyskinesis and its associated impact on the tennis athlete.

Kinetic Chain and Scapular Biomechanics

Optimal performance during the tennis serve involves the successive linkage of independent motions between the legs, trunk, shoulder girdle, and upper extremity. These coordinated motions in summation provide for the force generation necessary to hit the ball with maximal efficiency and are collectively referred to as the kinetic chain [1, 16, 17]. Throughout the kinetic chain, the lower extremities and core provide a stable base and are responsible for the largest amount of force generation. Kibler calculated that 51% of the total kinetic energy and 54% of the total force are generated through the legs, hips, and trunk [18]. The scapula concomitantly acts as a funnel for force transmission and serves as a fulcrum for stability throughout the rapid arm sequence, transmitting the energy through the elbow, hand, and ultimately the racket [17, 19, 20]. The most effective serve motion creates adequate knee flexion, trunk rotation, and core stability which allows the scapula to fully retract for maximum energy storage and transference [7, 21].

The kinetic chain during a tennis serve is delineated into five distinct phases (Fig. 1): wind-up, early cocking, late cocking, acceleration, and follow-through [1, 22, 23]. Within each phase, scapular motion is pivotal in maintaining concentric articulation of the glenohumeral joint (Fig. 2) [24]. The wind-up phase initiates energy storage in the upper and lower limbs as the serve motion begins and concludes when the ball is released from the non-dominant hand. The early cocking phase begins with glenohumeral external rotation and abduction. As the humerus approaches 90° of elevation, the trapezius and rhomboids contract to allow upward and external rotation of the scapula [24–26]. As the shoulder progresses into the late cocking phase, the synergistic contraction of the serratus anterior provides further scapular retraction which preserves the subacromial space [27]. This allows for clearance of the rotator cuff and the greater tuberosity as maximal abduction and external rotation of the shoulder is achieved [26]. During this time, the lower extremities are also loaded and begin to drive up, allowing for exaggerated external rotation of the glenohumeral joint [18, 23]. The acceleration phase subsequently begins as the shoulder initiates internal rotation using the pec minor to assist the scapula with anterior tilt, internal rotation, and protraction [9, 24]. This motion converts the stored energy potential from the previous phases to kinetic energy as the ball is eventually hit [16, 23]. Finally, the follow-through phase begins just after ball contact and consists of scapular downward and internal rotation to accommodate humeral flexion, internal rotation, and adduction [26]. Uncoupling at any point within this highly dynamic kinetic chain initiates compensatory mechanics and increased load on the remaining segments, predisposing athletes to injury and impaired performance [28, 29].

Scapular Dyskinesis

Maximized shoulder performance in the overhead athlete extensively relies upon a delicate balance between the muscular attachments of the scapula and its articulations with the clavicle, humerus, and thoracic cage. Scapular dyskinesis therefore is not a specific injury in itself; rather it is hypothesized to be an alteration in scapular function as a reaction to changes within its bony and muscular environment [7, 30]. In other words, scapular dyskinesis refers to the overall abnormal positioning and motion of the scapula.

Multiple etiologies have been associated with scapular dyskinesis, namely, (1) muscular imbalance and (2) force

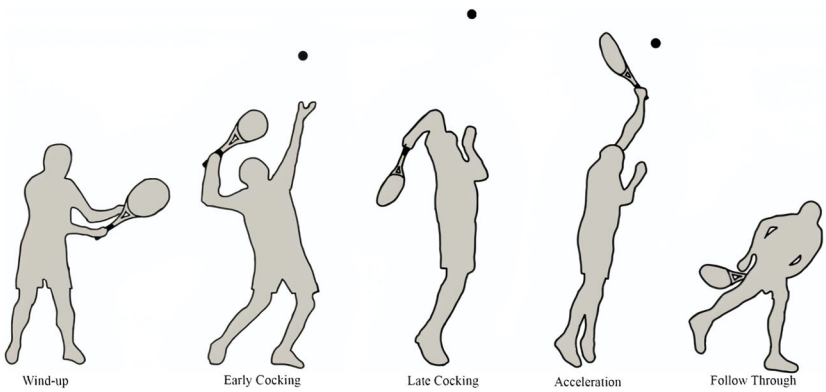

Fig. 1 Phases of the kinetic chain during tennis serve

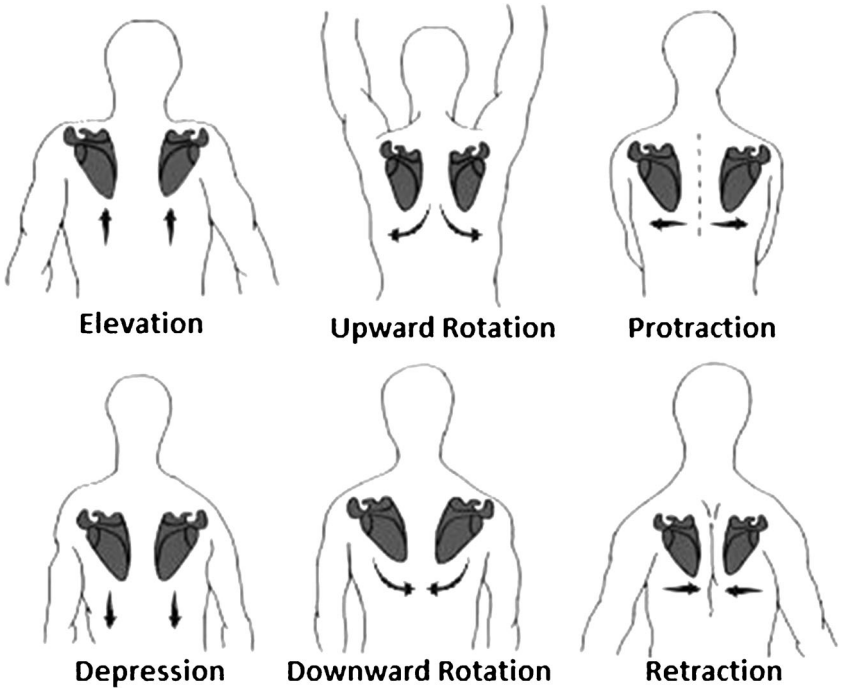

Fig. 2 Scapular planes of motion

uncoupling. First, muscle balance is vital as abnormal positioning disrupts the efficient transfer of energy along the kinetic chain. Much of scapular positioning relies upon synergistic coordination between the upper and lower trapezius, rhomboids, and serratus anterior [31]. Therefore, fatigue to the periscapular stabilizers caused by repetitive activities, such as those required in tennis, have been implicated in altered muscle activation patterns and scapular kinematics. Loss of coordinated protraction/retraction and insufficient elevation of the scapula results in glenoid ante-tilting (increased protraction or failure of proper retraction and inferior positioning of the scapula), which leads to narrowing of the subacromial arch and decreases the clearance of the rotator cuff under the acromion. This subjects the anterior labrum and capsule to greater shear forces as the arm is brought to provocative positions, which may manifest as clinical subacromial impingement during the late cocking, acceleration, and follow-through phases. Ebaugh et al. demonstrated increased scapular upward rotation in association with diminished humeral external rotation (ante-tilting) at mid-range levels of arm elevation after completion of a fatigue protocol [32]. Fatigue of the lower trapezius and serratus anterior can also cause closure of the subacromial arch by decreasing upward scapula rotation, leading to impingement symptoms. A more recent study by Umehara et al. showed increased scapular external rotation and increased activation in the rotator cuff and periscapular muscles with selective serratus anterior fatigue [33].

Force uncoupling as an etiology of scapular dyskinesis manifests mainly through neurologic disorders or underlying anatomic variation. Neuromuscular imbalance in the setting of medial or lateral scapular winging has been related to approximately 5% of patients with scapular dyskinesis [24]. Injury to the long thoracic nerve leads to serratus anterior dysfunction causing pronounced scapular medialization and elevation due to unopposed pull of the rhomboids and trapezius, respectively. Conversely, lesions of the spinal accessory nerve produce excessive lateralization and protraction of the scapula with the respective unopposed activity of the serratus anterior and pectoralis muscles. Underlying bony and ligamentous aberrations also play a key a role in scapular positioning and motion. Excessive cervical lordosis, thoracic kyphosis, or scoliosis can be a culprit in scapular maltracking by providing a suboptimal gliding surface with muscular activation [24]. Disruptions to the normal acromioclavicular articulation have also been shown to alter scapular kinematics. Gumina et al. found that 71% of patients with high-grade acromioclavicular injuries developed subsequent scapular dyskinesis [34]. Furthermore, clavicular shortening caused by fracture malunion demonstrated decreased posterior tilt of the scapula and also resulted in worse patient outcomes when compared with those without scapular dyskinesis [35, 36].

Kibler et al. provided a classification system for scapular dyskinesis based on the location of the scapular prominence: type I refers to the inferomedial border; type II refers to the entirety of the medial border; and type III refers to the superomedial border [24, 37]. These positions represent the net effect of the various etiologies and often require compensatory mechanisms from the surrounding musculature to achieve the desired function, placing them at risk for potential injury.

Clinical Evaluation

History and Physical Evaluation

When evaluating the tennis athlete, a comprehensive history should be obtained including information regarding the localization of the pain, in which motions/activities worsen or alleviate the pain, and if the patient has noticed a loss of ball control or velocity while playing. During physical examination of the scapula, visual comparison between the involved and contralateral side should be used to assess for any obvious winging. SICK (scapular malposition, inferior medial border prominence, coracoid pain and malposition, and scapular dyskinesis during motion) scapula syndrome is a consequence of scapular dyskinesis caused by overuse muscle fatigue defined by scapular asymmetry at rest but actively produces scapular dyskinesis as the shoulder goes through the throwing/serving cycle [8]. Patients presenting with SICK scapula syndrome often present with vague anterior shoulder pain with tenderness over the coracoid caused by pectoralis minor overpull and resultant scapular protraction [8]. Pain at the coracoid process with resisted forward flexion is common with a lack of active terminal forward flexion. Scapular asymmetry also should be assessed throughout shoulder range of motion, noting differences in muscle recruitment during active scapular retraction and protraction. In order to highlight subtle differences in the affected shoulder, the patient can be instructed to elevate and lower the upper extremity 3–5 times to accentuate muscular weakness [7]. Wall push-ups may be specifically used to assess weakness in the serratus anterior.

Provocative testing of the scapula includes the scapular retraction test (SRT) and the scapular assistance test (SAT) [7]. The SRT involves the patient's upper extremity being placed in an empty-can position while the examiner stabilizes the scapula in retraction (Fig. 3) [38]. The examiner further supports this position by placing their forearm along the medial border of the scapula. The corrected scapular motion provides a stable base of origin for the rotator cuff. A positive test therefore results in improved rotator cuff strength or additional terminal forward flexion without impingement symptoms. A positive SRT may also demonstrate scapular involvement in posterosuperior labral injuries [8, 24]. Dissipation of coracoid symptoms and increased forward flexion with scapular retraction test is considered diagnostic of SICK scapular syndrome. In other words, periscapular muscle inactivation or dysfunction is contributing to the patient's symptoms.

Similarly, the SAT evaluates scapular contributions to rotator cuff strength and impingement lesions. This test involves the examiner to provide an upward and laterally directed force along the inferomedial aspect of the scapula while stabilizing its superomedial border to correct the scapular plane of motion with active arm elevation (Fig. 4) [39]. Rabin et al. described a modified scapular assistance test in which the examiner places

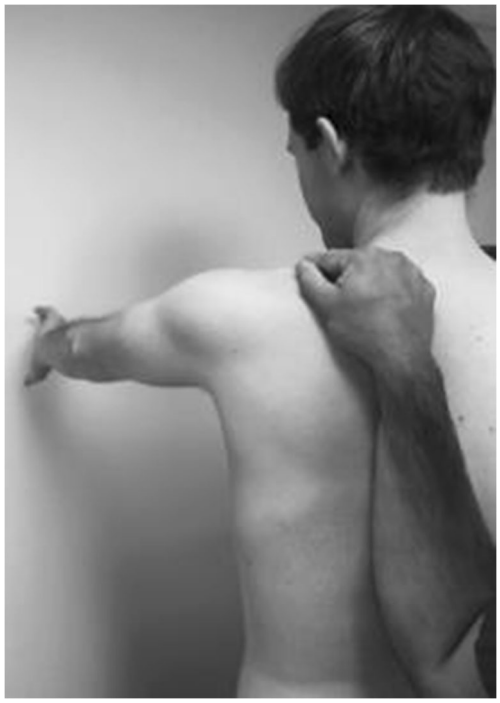

Fig. 3 Scapular retraction test

the palm of one hand over the inferior angle of the scapula and provides an upward and laterally directed force as the patient's arm is forward flexed [40]. The examiner's contralateral hand simultaneously pulls backward on the superior border of the scapula to provide a posterior tilt (Fig. 5). Both techniques

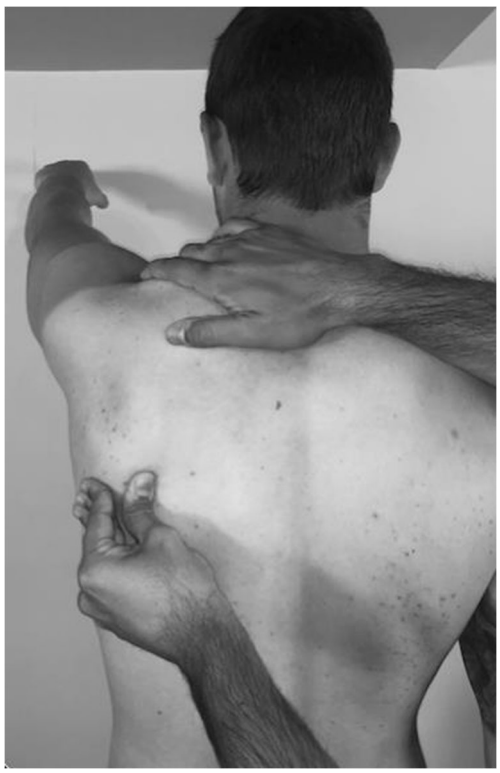

Fig. 4 Scapular assistance test

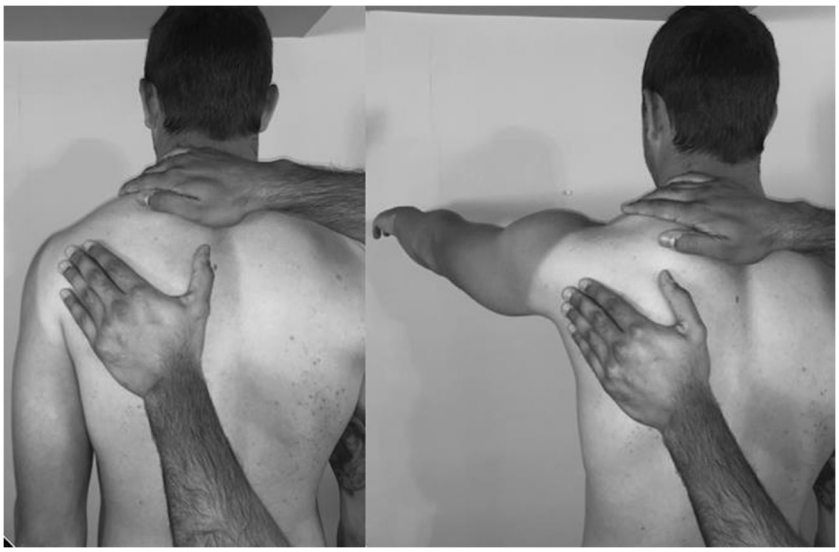

Fig. 5 Modified scapular assistance test

simulate the force-coupling activity of the lower trapezius and serratus anterior [24, 40]. A positive sign would reveal increased rotator cuff strength and alleviation of posterior impingement symptoms [8, 24]. Patients with subacromial impingement may also experience relief with the SAT since deficient acromial elevation can exacerbate these symptoms. Given the overlap of positive findings for both the SRT and SAT among various shoulder pathologies, there is some question regarding the validity of these tests given their subjective and qualitative nature [30]. A more recent systematic review highlighted the critical need for high-quality studies evaluating the inter- and intra-rater reliability for these manual correction tests since they are so widely used [41•]. Therefore, the authors suggest that although positive examination findings may not directly link causality to scapular dyskinesis, these tests should prompt the examiner for further investigation and to include scapular rehabilitation in the treatment protocol.

Evaluation of Tennis Activity

A comprehensive analysis of body mechanics may be beneficial to recognize causative or compensatory mechanisms throughout the kinetic chain. This involves an observational assessment of the service motion, paying close attention to the following key checkpoints, referred to as nodes: foot position, knee motion, hip motion, trunk motion, scapular position and motion, shoulder motion, shoulder over shoulder position, and long axis rotation (Fig. 6) [16, 17, 21, 42]. These specific nodes are pivotal segment positions and motions that are required for efficient linkage of the kinetic chain [21]. The feet serve as contact points with the ground, and optimal positioning provides the stability to allow maximum force generation [17]. In node one, proper technique would have the back foot behind lead foot; pathomechanics may lead to increased load on trunk or shoulder. The legs and core are responsible for providing the mass for a stable base. In node two, proper technique requires adequate knee flexion in cocking progressing to knee extension at ball impact. As the knees drive up from flexion to extension during the cocking phase, adequate hip and trunk motion are required for energy transference to the shoulder girdle. In nodes 3 and 4, proper technique requires hip/trunk counter rotation away from the court in cocking phase. Hip and trunk rotation are especially important as the back leg swings forward throughout the progression of the kinetic chain to eventually create the shoulder over shoulder motion at ball impact [21]. This was highlighted in a comparative kinematic study in which tennis players demonstrated increased pelvis and trunk rotation to achieve maximal angular velocities when compared with those of handball and volleyball players [43]. The scapula and subsequently the shoulder act as a funnel for force regulation to allow the upper extremity to transmit energy through the racket with long axis rotation during the follow-through phase [21]. A coupled scapular retraction/arm rotation with proper technique allows the player to achieve cocking in the scapular plane with a back leg to front leg motion to create a "shoulder over shoulder" motion at ball impact and long axis rotation into ball impact/follow-through. Maximal efficiency of the tennis serve utilizes proper sequencing of these nodes throughout the kinetic chain which in turn places the least amount of stress on the shoulder [21]. Identification of aberrant mechanics at any particular node warrants a more detailed evaluation to diagnose potential contributing factors.

Associated Pathologies

There are many associated pathologies that may mask or accompany underlying scapular dyskinesis tennis athletes. Some of these include glenohumeral internal rotation

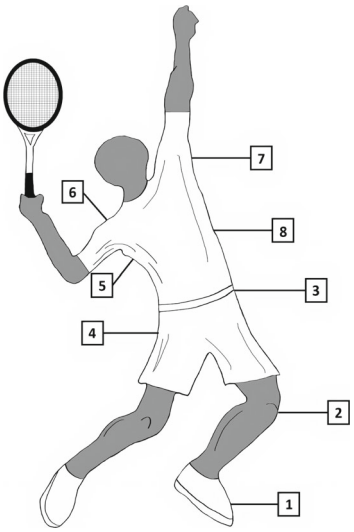

Fig. 6 Examination of specific tennis serve nodes

Node	*Clinical Significance*
1. **Foot Position**	Evaluate hip and/or trunk flexibility and strength; pathomechanics may lead to increased load on trunk or shoulder.
2. **Knee Motion**	Evaluate hip and knee strength; pathomechanics may lead to increased load on anterior shoulder and medial elbow.
3. **Hip Motion**	Evaluate hip and trunk flexion flexibility and strength; pathomechanics may lead to increased load on shoulder and trunk
4. **Trunk Motion**	Evaluate hip, trunk, and shoulder flexibility; pathomechanics may lead to increased load on anterior shoulder and possibly "slow arm" from increased load on abdominals.
5. **Scapular Position**	Evaluate scapular strength and mobility; pathomechanics may lead to increased internal and external impingement with increased load on rotator cuff muscles.
6. **Shoulder/Scapular Motion**	Evaluate scapular and shoulder strength and flexibility; pathomechanics may lead to increased load on anterior shoulder with potential internal impingement.
7. **Shoulder Over Shoulder**	Evaluate front hip strength and flexibility with back hip weakness; pathomechanics may lead to increased load on abdominals.
8. **Long Axis Rotation**	Evaluate glenohumeral rotation; pathomechanics may lead to increased load on medial elbow.

deficiency (GIRD), SLAP tears, shoulder impingement, and rotator cuff pathology.

Glenohumeral Internal Rotation Deficiency

GIRD is a common finding well documented in overhead athletes [8, 44–46]. This pathology is thought to occur from repetitive activities, such as throwing or serving, which induce posteroinferior capsular tightening and attenuation of the anterior ligamentous structures. This results in altered shoulder biomechanics with a posterosuperior shift in the glenohumeral rotation point. The relative immobility of the posterior capsule also induces excessive scapular protraction and anterior tilt. These forces combined accentuate the peel-back mechanism on the posterosuperior labrum in the late cocking phase, ultimately leading to tensile failure, SLAP tears, and subsequent pain with overhead activities [8, 47].

Shoulder Impingement and Rotator Cuff Tears

Shoulder impingement and rotator cuff tears in the overhead athlete frequently coexist and have been associated with altered scapular kinematics [10, 11, 24, 48–50]. The scapula normally functions to provide a stable platform for the rotator cuff to generate adequate humeral head compression for stability and upper extremity rotation for mobility. However in overhead athletes, the repetitive and often supraphysiologic impingement between the posterosuperior glenoid and greater tuberosity may lead to the development of partial articular-sided rotator cuff tears and labral shearing as originally described by Walch et al. [51] A more recent kinematic study performed in tennis players supports this theory as it demonstrated posterosuperior impingement during the late cocking phase of the service motion in nearly 75% of its population [49]. Furthermore, the study showed concerning subacromial impingement with superior translation of the humeral head as the arm approached 65° of abduction [49]. Although the exact mechanism remains unclear, increased scapular protraction, often found in patients with scapular dyskinesis, may further diminish subacromial clearance and predispose the rotator cuff to bursal-sided wear [24]. An animal model was used to demonstrate this causative theory by inducing scapular winging and evaluating its effect on rotator cuff histology. The study found that altered scapular motion induced histologic changes and increased collagen type III expression consistent with tendon pathology [52]. Both the SRT and SAT assess scapular involvement with rotator cuff pathology; however, negative findings still warrant further provocative testing of the individual rotator cuff muscles to rule out injury.

Treatment Options

When considering the treatment options, it is important to consider a loss of ideal concavity compression and functional glenohumeral stability, which is a main pathomechanical feature of the disabled throwing shoulder (DTS) [17]. This can result from a mixture of alteration of muscle force couples, scapular dyskinesis, internal/total rotation deficiency, rotator cuff disease, and/or labral injury [53–57]. Any combination of these pathologies may result in a loss of performance complaints (i.e., loss of velocity and accuracy along with clinical symptoms of pain, clicking, sliding, weakness, and injury) [17].

Rehabilitation

The mainstay of treatment for scapular dyskinesis remains a comprehensive physical therapy regimen concentration on improving scapular control, core, and rotator cuff strengthening with the goal of improving the stability of the shoulder. Initial treatment should focus on addressing derangements in the proximal aspects of the kinetic chain identified during node analysis. This establishes stability of the core musculature to maximize efficiency in force generation and activation sequencing of the periscapular stabilizing muscles [7]. Once this has been achieved, focus should be shifted to the periscapular musculature to restore optimal scapular positioning. This may present as two underlying conditions, lack of soft tissue flexibility or lack of muscular performance, although rarely they are mutually exclusive [50]. Rehabilitation of flexibility deficits should focus on the core muscles involved in periscapular and glenohumeral stabilization [7, 58]. These include, but are not limited to, the trapezius, the pectoralis major and minor, the serratus anterior, the rhomboids, and the rotator cuff muscles [7, 58]. Additionally, angular stretches such as the "sleeper stretch" and "cross body" stretch have been shown to be effective in restoring range of motion and increasing the acromiohumeral distance in the setting of posterior capsular hypertrophy [58, 59].

Rehabilitation of muscular performance is categorized into three separate phases: active conscious muscle control, muscle control and strength necessary for daily activities, and advanced control during sporting activities [58]. The first stage focuses on improving proprioception and normalizing resting scapular position. The patient is advanced through scapular orientation exercises and conscious movement training which allow for transient changes in motor strategies and upper limb kinematics [58, 60]. During this time, postural mechanics are revisited and emphasized to limit thoracic kyphosis and associated scapular protraction. The second phase focuses on concurrent muscular activation to simulate activities of daily life. This involves the utilization of open- and closed-chain activities that are consistent with the functional requirements of the patient [7, 24, 58]. Simple exercises mimicking problematic functional tasks can be included in this stage and progressively advanced with increased holding time, repetitions, or resistance [58]. The last stage involves general periscapular strengthening exercises used to increase muscular strength and endurance. During this phase, maintaining muscular balance is fine-tuned through sport-specific motions and exercises [58].

Multiple studies have demonstrated satisfactory results with non-operative physical therapy regimens incorporating scapular stabilization techniques in the treatment of full-thickness rotator cuff tears, impingement syndrome, and SLAP tears [60–63]. Surgical management should be considered after failure of an exhaustive trial of physical therapy. Operative intervention may be needed to recreate the concavity compression by reducing the capsular volume. In these situations, the senior author (ASC) prefers a pinch-tuck procedure in these situations to plicate the anterior-inferior glenohumeral ligament [64]. Lastly, the goal of surgical intervention should aim to restore the patient's functional anatomy since many overhead athletes have an altered physiologic baseline that allows them to excel at their individual sport. These findings may suggest that changes in scapular kinematics do not adequately explain such improvements in pain and function and indeed question whether scapular dyskinesis is a modifiable risk factor.

Conclusion

The tennis athlete is highly susceptible to shoulder pathologies given the repetitive and highly dynamic overhead load required for competition. The examining clinician should have a thorough understanding of the kinetic chain involved during the tennis serving motion to recognize key nodal deficiencies. The scapula plays a pivotal role in force transmission through the shoulder girdle, converting potential energy developed in the legs and trunk to kinetic energy dissipated in the upper extremity as the ball is struck. Scapular dyskinesis, which involves the pathologic motion and positioning of the scapula, is a common breaking point in the kinetic chain and has been implicated in the successive injury of distal structures through compensatory mechanisms. Diagnosis involves a comprehensive examination which may include evaluating shoulder symptoms with simulated correction of scapular positioning. A detailed evaluation of the specific tennis nodes should be performed to assess potential points of breakdown within the kinetic chain. The mainstay of treatment for scapular dyskinesis remains an extensive course of physical therapy involving scapular proprioceptive retraining, strengthening, and sport-specific exercises. Operative management should occur at addressing causative factors that may inhibit scapular motion only if rehabilitative measures have failed.

Compliance with Ethical Standards

Conflict of Interest Sundeep S. Saini, Sarav S. Shah, and Alan S. Curtis declare that they have no conflicts of interest pertinent to this paper.

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. van der Hoeven H, Kibler WB. Shoulder injuries in tennis players. Br J Sports Med. 2006;40(5):435–40.

2. Lehman RC. Shoulder pain in the competitive tennis player. Clin Sports Med. 1988;7(2):309–27.
3. Abrams GD, Renstrom PA, Safran MR. Epidemiology of musculoskeletal injury in the tennis player. Br J Sports Med. 2012;46(7):492–8.
4. Hutchinson MR, Laprade RF, Burnett QM 2nd, Moss R, Terpstra J. Injury surveillance at the USTA Boys' Tennis Championships: a 6-yr study. Med Sci Sports Exerc. 1995;27(6):826–30.
5. Winge S, Jorgensen U, Lassen NA. Epidemiology of injuries in Danish championship tennis. Int J Sports Med. 1989;10(5):368–71.
6.• Hickey D, Solvig V, Cavalheri V, Harrold M, McKenna L. Scapular dyskinesis increases the risk of future shoulder pain by 43% in asymptomatic athletes: a systematic review and meta-analysis. Br J Sports Med. 2018;52(2):102–10 **This systematic review demonstrated that athletes with scapular dyskinesis have approximately a 43% greater risk of developing shoulder pain than those who do not, despite being asymptomatic.**
7. Kibler WB, Ludewig PM, McClure PW, Michener LA, Bak K, Sciascia AD. Clinical implications of scapular dyskinesis in shoulder injury: the 2013 consensus statement from the 'Scapular Summit'. Br J Sports Med. 2013;47(14):877–85.
8. 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):641–61.
9. McClure PW, Michener LA, Sennett BJ, Karduna AR. Direct 3-dimensional measurement of scapular kinematics during dynamic movements in vivo. J Shoulder Elb Surg. 2001;10(3):269–77.
10. Sonnery-Cottet B, Edwards TB, Noel E, Walch G. Rotator cuff tears in middle-aged tennis players: results of surgical treatment. Am J Sports Med. 2002;30(4):558–64.
11. Mell AG, LaScalza S, Guffey P, et al. Effect of rotator cuff pathology on shoulder rhythm. J Shoulder Elb Surg. 2005;14(1 Suppl S):58s–64s.
12. Clarsen B, Bahr R, Andersson SH, Munk R, Myklebust G. Reduced glenohumeral rotation, external rotation weakness and scapular dyskinesis are risk factors for shoulder injuries among elite male handball players: a prospective cohort study. Br J Sports Med. 2014;48(17):1327–33.
13. Lopes AD, Timmons MK, Grover M, Ciconelli RM, Michener LA. Visual scapular dyskinesis: kinematics and muscle activity alterations in patients with subacromial impingement syndrome. Arch Phys Med Rehabil. 2015;96(2):298–306.
14.• Shitara H, Kobayashi T, Yamamoto A, et al. Prospective multifactorial analysis of preseason risk factors for shoulder and elbow injuries in high school baseball pitchers. Knee Surg Sports Traumatol Arthrosc. 2017;25(10):3303–10 **This study brings to light the recent controversy in the role of scapular dyskinesis as it pertains to shoulder injuries in the overhead athlete. This study found no significant association between a preseason diagnosis of scapular dyskinesis and subsequent shoulder injuries in a cohort of 105 high school baseball pitchers.**
15. Myers JB, Oyama S, Hibberd EE. Scapular dysfunction in high school baseball players sustaining throwing-related upper extremity injury: a prospective study. J Shoulder Elb Surg. 2013;22(9):1154–9.
16. Kovacs M, Ellenbecker T. An 8-stage model for evaluating the tennis serve: implications for performance enhancement and injury prevention. Sports Health. 2011;3(6):504–13.
17. Kibler WB, Wilkes T, Sciascia A. Mechanics and pathomechanics in the overhead athlete. Clin Sports Med. 2013;32(4):637–51.
18. Kibler WB. Biomechanical analysis of the shoulder during tennis activities. Clin Sports Med. 1995;14(1):79–85.
19. Elliott BC, Marshall RN, Noffal GJ. Contributions of upper limb segment rotations during the power serve in tennis. J Appl Biomech. 1995;11(4):433–42.
20. Hirashima M, Kadota H, Sakurai S, Kudo K, Ohtsuki T. Sequential muscle activity and its functional role in the upper extremity and trunk during overarm throwing. J Sports Sci. 2002;20(4):301–10.
21. Lintner D, Noonan TJ, Kibler WB. Injury patterns and biomechanics of the athlete's shoulder. Clin Sports Med. 2008;27(4):527–51.
22. Ryu RK, McCormick J, Jobe FW, Moynes DR, Antonelli DJ. An electromyographic analysis of shoulder function in tennis players. Am J Sports Med. 1988;16(5):481–5.
23. Abrams GD, Sheets AL, Andriacchi TP, Safran MR. Review of tennis serve motion analysis and the biomechanics of three serve types with implications for injury. Sports Biomechanics. 2011;10(4):378–90.
24. Kibler WB, Sciascia A, Wilkes T. Scapular dyskinesis and its relation to shoulder injury. J Am Acad Orthopaedic Surg. 2012;20(6):364–72.
25. Myers JB, Laudner KG, Pasquale MR, Bradley JP, Lephart SM. Scapular position and orientation in throwing athletes. Am J Sports Med. 2005;33(2):263–71.
26. Rogowski I, Creveaux T, Sevrez V, Cheze L, Dumas R. How does the scapula move during the tennis serve? Med Sci Sports Exerc. 2015;47(7):1444–9.
27. Forthomme B, Crielaard JM, Croisier JL. Scapular positioning in athlete's shoulder : particularities, clinical measurements and implications. Sports Med (Auckland, NZ). 2008;38(5):369–386.
28. Elliott B, Fleisig G, Nicholls R, Escamilia R. Technique effects on upper limb loading in the tennis serve. J Sci Med Sport. 2003;6(1):76–87.
29. Wilk KE, Macrina LC, Fleisig GS, Porterfield R, Simpson CD II, 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.
30. Wright AA, Wassinger CA, Frank M, Michener LA, Hegedus EJ. Diagnostic accuracy of scapular physical examination tests for shoulder disorders: a systematic review. Br J Sports Med. 2013;47(14):886–92.
31. Lee B, Kim D, Jang Y, Jin H. Three-dimensional in vivo scapular kinematics and scapulohumeral rhythm: a comparison between active and passive motion. J Shoulder Elb Surg. 2020;29(1):185–94.
32. Ebaugh DD, McClure PW, Karduna AR. Scapulothoracic and glenohumeral kinematics following an external rotation fatigue protocol. J Orthop Sports Phys Ther. 2006;36(8):557–71.
33. Umehara J, Kusano K, Nakamura M, Morishita K, Nishishita S, Tanaka H, et al. Scapular kinematic and shoulder muscle activity alterations after serratus anterior muscle fatigue. J Shoulder Elb Surg. 2018;27(7):1205–13.
34. Gumina S, Carbone S, Postacchini F. Scapular dyskinesis and SICK scapula syndrome in patients with chronic type III acromioclavicular dislocation. Arthroscopy. 2009;25(1):40–5.
35. Shields E, Behrend C, Beiswenger T, Strong B, English C, Maloney M, et al. Scapular dyskinesis following displaced fractures of the middle clavicle. J Shoulder Elb Surg. 2015;24(12):e331–6.
36. Matsumura N, Ikegami H, Nakamichi N, Nakamura T, Nagura T, Imanishi N, et al. Effect of shortening deformity of the clavicle on scapular kinematics: a cadaveric study. Am J Sports Med. 2010;38(5):1000–6.
37. Kibler WB, Uhl TL, Maddux JW, Brooks PV, Zeller B, McMullen J. Qualitative clinical evaluation of scapular dysfunction: a reliability study. J Shoulder Elb Surg. 2002;11(6):550–6.
38. 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.
39. Kibler WB. The role of the scapula in athletic shoulder function. Am J Sports Med. 1998;26(2):325–37.

40. Rabin A, Irrgang JJ, Fitzgerald GK, Eubanks A. The intertester reliability of the scapular assistance test. J Orthop Sports Phys Ther. 2006;36(9):653–60.
41.• Lange T, Struyf F, Schmitt J, Lützner J, Kopkow C. The reliability of physical examination tests for the clinical assessment of scapular dyskinesis in subjects with shoulder complaints: a systematic review. Phys Ther Sport. 2017;26:64–89 **This is a systematic review that highlights the lack of studies demonstrating inter- and intra-rater reliability for the most commonly used physical examination tests for the clinical assessment of scapular dyskinesis.**
42. Myers NL, Kibler WB, Lamborn L, Smith BJ, English T, Jacobs C, et al. Reliability and validity of a biomechanically based analysis method for the tennis serve. Int J Sports Phys Ther. 2017;12(3):437–49.
43. Wagner H, Pfusterschmied J, Tilp M, Landlinger J, von Duvillard SP, Müller E. Upper-body kinematics in team-handball throw, tennis serve, and volleyball spike. Scand J Med Sci Sports. 2014;24(2):345–54.
44. Chou PP, Chou YL, Wang YS, Wang RT, Lin HT. Effects of glenohumeral internal rotation deficit on baseball pitching among pitchers of different ages. J Shoulder Elb Surg. 2018;27(4):599–605.
45. Rose MB, Noonan T. Glenohumeral internal rotation deficit in throwing athletes: current perspectives. Open Access J Sports Med. 2018;9:69–78.
46. Thomas SJ, Swanik KA, Swanik CB, Kelly JD. Internal rotation deficits affect scapular positioning in baseball players. Clin Orthop Relat Res. 2010;468(6):1551–7.
47. 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):637–40.
48. McClure PW, Michener LA, Karduna AR. Shoulder function and 3-dimensional scapular kinematics in people with and without shoulder impingement syndrome. Phys Ther. 2006;86(8):1075–90.
49. Ladermann A, Chague S, Kolo FC, Charbonnier C. Kinematics of the shoulder joint in tennis players. J Sci Med Sport. 2016;19(1):56–63.
50. Cools AM, Declercq G, Cagnie B, Cambier D, Witvrouw E. Internal impingement in the tennis player: rehabilitation guidelines. Br J Sports Med. 2008;42(3):165–71.
51. 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.
52. Reuther KE, Thomas SJ, Tucker JJ, Yannascoli SM, Caro AC, Vafa RP, et al. Scapular dyskinesis is detrimental to shoulder tendon properties and joint mechanics in a rat model. J Orthop Res. 2014;32(11):1436–43.
53. Kibler WB, Kuhn JE, Wilk K, Sciascia A, Moore S, Laudner K, et al. The disabled throwing shoulder: spectrum of pathology-10-year update. Arthroscopy. 2013;29(1):141–61 **e126**.
54. Weiser WM, Lee TQ, McMaster WC, McMahon PJ. Effects of simulated scapular protraction on anterior glenohumeral stability. Am J Sports Med. 1999;27(6):801–5.
55. Mihata T, Jun BJ, Bui CN, et al. Effect of scapular orientation on shoulder internal impingement in a cadaveric model of the cocking phase of throwing. J Bone Joint Surg Am. 2012;94(17):1576–83.
56. Harryman DT 2nd, Sidles JA, Clark JM, McQuade KJ, Gibb TD, Matsen FA 3rd. Translation of the humeral head on the glenoid with passive glenohumeral motion. J Bone Joint Surg Am. 1990;72(9):1334–43.
57. 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):824–31.
58. Cools AM, Struyf F, De Mey K, Maenhout A, Castelein B, Cagnie B. Rehabilitation of scapular dyskinesis: from the office worker to the elite overhead athlete. Br J Sports Med. 2014;48(8):692–7.
59. Manske RC, Meschke M, Porter A, Smith B, Reiman M. A randomized controlled single-blinded comparison of stretching versus stretching and joint mobilization for posterior shoulder tightness measured by internal rotation motion loss. Sports Health. 2010;2(2):94–100.
60. Struyf F, Nijs J, Mollekens S, Jeurissen I, Truijen S, Mottram S, et al. Scapular-focused treatment in patients with shoulder impingement syndrome: a randomized clinical trial. Clin Rheumatol. 2013;32(1):73–85.
61. De Mey K, Danneels L, Cagnie B, Cools AM. Scapular muscle rehabilitation exercises in overhead athletes with impingement symptoms: effect of a 6-week training program on muscle recruitment and functional outcome. Am J Sports Med. 2012;40(8):1906–15.
62. Harris JD, Pedroza A, Jones GL. Predictors of pain and function in patients with symptomatic, atraumatic full-thickness rotator cuff tears: a time-zero analysis of a prospective patient cohort enrolled in a structured physical therapy program. Am J Sports Med. 2012;40(2):359–66.
63. Edwards SL, Lee JA, Bell JE, Packer JD, Ahmad CS, Levine WN, et al. Nonoperative treatment of superior labrum anterior posterior tears: improvements in pain, function, and quality of life. Am J Sports Med. 2010;38(7):1456–61.
64. Shah SS, Curtis AS. A 22-year-old female tennis player with shoulder pain. In: Kibler WB, Sciascia AD, editors. Mechanics, pathomechanics and injury in the overhead athlete: a case-based approach to evaluation, diagnosis and management. Cham: Springer International Publishing; 2019. p. 261–8.