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The Shoulder at Risk: Scapular Dyskinesis and Altered Glenohumeral Rotation☆

William Benjamin Kibler, MD, and Aaron Sciascia, MS, ATC, PES

The shoulder at risk is a concept that describes alterations in the kinetic chain (the sequential coordinated and task-specific development of force) and shoulder that produce an impairment of optimum function. The glenohumeral (GH) structures may be susceptible to injury when exposed to the inherent high demands of throwing, creating the disabled throwing shoulder. Although multiple factors can lead to a shoulder at risk, the 2 most common factors are scapular dyskinesis and alterations in GH motion. Dyskinesis represents an alteration of static scapular position or dynamic scapular motion in coordination with arm motion and is best considered an impairment of optimum shoulder function, with potential harmful effects on the anatomical structures. Altered GH rotation creates a shoulder at risk by decreasing the rotation and increasing the amount of translation. Both impairments are capable of altering shoulder motions and loads and should be considered contributors to the shoulder at risk of injury. A focalized physical examination should be utilized to not only initially assess for the presence or absence of these impairments but also periodically assess throughout training or competition as both impairments can develop overtime even in the absence of injury.
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Introduction

The overhead throwing or serving motion is a complex dynamic activity involving the entire body. It results in the performance of a task that requires repetitive high velocity, high load, and large range of motion activities with a high degree of precision. Optimum performance with minimal injury risk requires precise glenohumeral (GH) ball-and-socket kinematics.[1] The kinematics result from optimal scapulohumeral bony alignment ($\pm 30^\circ$ anterior or posterior angulation) throughout the full arc of arm motion,[2,3] muscle activation in co-contraction force couples,[1,4] full range of GH rotational motion,[5-7] and optimal labral and ligamentous integrity.[1] These factors produce maximal concavity or compression that optimizes the functional stability that allows protection of the GH joint structures and efficient transfer of forces to accomplish the tasks of throwing.[8,9] Any factor that alters this complex biomechanical interaction may produce inefficient mechanics and place the shoulder at increased risk of injury.

The overhead throwing motion is developed and regulated through a sequentially coordinated and task-specific kinetic chain of force development and a sequentially activated kinematic chain of body positions and motions.[10] The kinematics of both the baseball throw and tennis serve have been well described and may be broken down into phases.[11-13] These descriptions show how muscles can move the individual segments and show the temporal sequence of the motions. The kinetics are not well described but are important towing to the forces and motions that are developed. These forces and motions are applied to all of the body segments to allow their summation, regulation, and transfer throughout the segments to result in performance of the task of throwing or hitting the ball. The term "kinetic chain" is used collectively to describe both of these mechanical linkages.

The kinetic chain develops large ranges of motion, high rotational velocities, and large compression and distraction forces at the GH joint.[1,14,15] A relatively small proportion of forces and loads are actually produced by the structures around the shoulder.[16-20] Most are developed by the ground reaction force and core activation[16,21] and transferred through the shoulder articulation to the hand.[13,21,22]

Shoulder Center of Kentucky, Lexington Clinic, Lexington, KY.
☆https://www.shouldercenterofky.com
Address reprint requests to Aaron Sciascia, MS, ATC, PES, Shoulder Center of Kentucky, Lexington Clinic, 1221 South Broadway, Lexington, KY 40504 E-mail: ascia@lexclin.com

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The overhead athlete with a painful shoulder has been shown to have a multitude of possible causative factors contributing to the presenting complaints of pain and decreased function, either by causing the anatomical injury or increasing the dysfunction from the injury. They may be alterations in anatomy, physiology, or biomechanics. They can combine to produce an alteration in the normal mechanics, resulting in pathomechanics that may create decreased efficiency in the kinetic chains, impaired performance, increased injury risk, or actual injury.[16,22,23] These pathomechanics contribute to the "disabled throwing shoulder,"[24] a general term that describes the limitations of function that exist in symptomatic overhead athletes—from baseball players to tennis players—in that they cannot optimally perform the task of throwing or hitting the ball. In the large percentage of cases, the disable throwing shoulder is the result of a "cascade to injury,"[24] a process in which the body's response to the inherent demands of throwing or hitting results in a series of alterations throughout the kinetic chain that can affect the optimal function of all segments in the chain. The shoulder at risk is a concept that describes alterations in the kinetic chain and shoulder that produce an impairment of optimum function, and it may place the GH structures at higher risk of injury when exposed to the inherent high demands of throwing, creating the disabled throwing shoulder.[24]

In a closed system such as the kinetic chain, alteration in one area creates changes throughout the entire system.[1] This is known as the "catch up" phenomenon where the changes in the interactive moments alter the forces in the distal segments.[16,18] The increased forces place extra stress on the distal segments, which often result in the sensation of pain or actual anatomical injury. Multiple types of alterations have been reported in the proximal segments of the kinetic chain, including hamstring tightness, hip weakness or inflexibility, and back injury.[10,13,25-30] These result in increased loads on the GH joint and are associated with injury.[13] This article specifically reviews scapular dyskinesis and alterations in GH motion that can be associated with the shoulder at risk. It reviews current knowledge in these areas and presents current thought on some of the unknown areas of the sometimes controversial topic.

Scapular Dyskinesis

Scapular roles in shoulder function include positioning the bone to act as a congruent glenoid for ball-and-socket kinematics, providing a stable base for muscle activation, providing adequate subacromial space for the moving humerus, and integrating movement throughout the entire overhead motion.[31-33] The most effective motion to achieve these roles is retraction, external rotation, posterior tilt, and downward rotation in cocking, and controlled protraction, internal rotation, and upward rotation in follow-through.[10,11,32,34,35]

Scapular dys- (alteration of) kinesis (forceful motion) is an alteration of dynamic motion that creates less-than-optimal scapular function in the kinetic chain (Fig. 1). It has multiple causes including neurologic (long thoracic or accessory nerve palsy), bony (clavicle fracture, acromioclavicular joint injury), or most commonly soft tissue (muscle imbalance, muscle inflexibility, muscle activation inhibition, or capsular contracture).[33,36,37]

Figure 1 Example of scapular dyskinesis showing medial border prominence when lowering arm from an elevated position. (Color version of figure is available online.)

Scapular dyskinesis is also seen in virtually every athlete with the disabled throwing shoulder. Dyskinesis represents an alteration of static scapular position or dynamic scapular motion in coordination with arm motion. The altered position and motions create a loss of control of retraction and posterior tilt, resulting in protraction, anterior tilt, and excessive internal rotation. Dyskinesis is best considered an impairment of optimum shoulder function, with potential harmful effects on the anatomical structures. Excessive scapular protraction is associated with increased anterior capsular strain contributing to acquired microinstability.[38] Protraction is also associated with symptoms of external impingement[37,39-41] and rotator cuff tendon changes.[42] Dyskinesis is associated with decreased demonstrated abduction and external rotation strength, compromising the dynamic concavity or compression function.[43,44] Finally, increased internal rotation is associated with internal impingement, increasing the area of rotator cuff impingement and the compressive load on the superior labrum and rotator cuff.[45,46] The effect of these factors is confirmed by clinical data. Scapular dyskinesis is observed in 94% of athletes with the disabled throwing shoulder and is associated with 67%-100% of all shoulder injuries.[10,47-49] Therefore, clinical evaluation for the presence or absence of dyskinesis should be performed in all athletes with shoulder symptoms.

Scapular Examination

The clinical evaluation of the scapula should be inclusive for all possible local and distant contributors to dyskinesis. The scapular examination can be done mainly by a screening examination with particular attention given to the areas proximal to the scapula (knee, hip, and trunk). These areas are important to screen for underlying impairments (weakness, tightness, etc.) as they contain the larger, power-generating segments within the kinetic chain and deficiencies in these areas can have a negative effect on scapular function. Maneuvers that assess single-leg stability such as Trendelenberg stance and single-leg squat can be employed as well as tests for hip rotation, lumbar flexion or extension, lumbar lordosis or thoracic kyphosis, and cervical lordosis.

The scapular examination should concentrate on the evaluation for the presence or absence of scapular dyskinesis and determine the possible effects on the symptoms and signs of the dysfunction. A panel of experienced researchers and clinicians reviewed the literature and developed a consensus document reflecting best practices for the scapular examination. A total of 6 main components should comprise the examination of the scapula[37,50]: (1) localization of periscapular symptoms, (2) observational scapular assessment, (3) manual muscle testing, (4) posture, (5) muscle tightness, and (6) symptom or sign alteration maneuvers. The results of the examination would aid in establishing the involvement of the scapula and some of the causative factors of the dyskinesis and would help guide treatment and rehabilitation.

Localization of Symptoms

Localization of pain is helpful in the clinical examination. Pain to palpation is commonly found along the medial scapular border, especially close to the scapular spine. Other common areas are the upper trapezius or levator scapulae area along the superior edge, the serratus anterior, the latissimus dorsi along the lateral scapular border, and the anterior coracoid muscles, pectoralis minor, and short head of the biceps. These point tender areas are thought to represent tight, shortened, or spastic muscles and are managed by mobilization techniques. It is suggested to palpate along the medial border, beginning at the superior aspect at the corner of the spine of the scapula and ending at the most inferior aspect of the medial border.

Observational Scapular Assessment

Considering scapular dyskinesis is best classified as a musculoskeletal impairment, and observational assessment for identifying scapular dyskinesis is recommended. The advocated evaluation method involves using the medial border of the scapula as the landmark for scapular orientation, and it uses both static position at rest and dynamic motion with arm elevation as observation points.[37,50-53] Medial border prominence patterns may be predominantly inferior medial border (type I), entire medial border (type II), or superior medial border pattern (type III), or may be a combination of these patterns. However, research has shown that dynamic scapular motion is complex where multiple "types" of dyskinesis can occur simultaneously.[51] Therefore, a simplified assessment and classification method has been developed to overcome this concern.[51-53]

Dynamic scapular motions may be evaluated by having the patient move the arms in ascent and descent 3-5 times. This would usually bring out any weakness in the muscles and display the dyskinetic patterns. Motion in forward flexion is most likely to demonstrate medial border prominence. Prominence of any part of the medial border is recorded in a "yes" (dyskinesis present) or "no" (dyskinesis not present) fashion.[40] Dyskinesis is defined as the presence of either winging (prominence of any portion of the medial border or inferior angle away from the thorax) or dysrhythmia (premature or excessive or stuttering motion during elevation and lowering). This evaluation system shows a clinical utility of 0.64-0.84 between the clinical examination and the biomechanical findings.[51] If necessary, more repetitions, up to 10, or addition of 3-5 lbs weights would highlight the weakness even more.[52,53] Once this has been demonstrated, tests for strength and flexibility can help determine some of the causative factors.

Manual Muscle Testing

The multiple muscle attachments at and around the shoulder and scapula do not allow muscles to be isolated for testing. However, the maneuvers typically labeled as muscle tests for specific muscles have been to include activation of other muscles as well.[54-61] A test advocated to assess the integrity of the lower trapezius and serratus anterior muscles is that of the low row.[54] To perform this maneuver, the patient stands with the involved arm resting at the side with the palm facing posteriorly. The patient is instructed to extend his or her trunk and push his or her hand maximally against an examiner's resistance in the direction of shoulder extension and instructed to retract and depress the scapula. This maneuver assesses both muscles' ability to actively stabilize the scapula while providing the examiner a visual depiction of muscle contraction. Additionally, this maneuver has been shown to evoke activation of the rhomboid muscles as well.[59] Therefore, similar to other muscle testing maneuvers, the low row is not specifically a test for either the lower trapezius or serratus anterior but instead a test for scapular retraction, external rotation, and depression. Other tests such as active scapular squeezing or pinching and the wall push-up have also been advocated as maneuvers to employ to assess scapular muscle function.[31]

Posture and Flexibility

Many authors have suggested that forward head posture and increased thoracic kyphosis may contribute to scapular protraction and lead to adaptive shortening of postural muscles or muscular strength imbalances.[62-65] A protracted scapular position may be associated with a narrowed subacromial space,[66,67] upright posture with increased subacromial space,[68] and a flexed thoracic spine and forward shoulder position that alters scapular motion and results in diminished force output with elevation.[62] Adaptive shortening of the pectoralis minor muscle has been identified as a contributor to abnormal scapular kinematics and implicated as a factor that may contribute to shoulder impingement syndrome.[69,70] Although different assessment methods have been described to measure pectoralis minor length, the practicality and validity of the measures is limited.[71,72] At minimum, coracoid-based inflexibility can be assessed by palpation of the pectoralis minor and the short head of the biceps brachii at their insertion

Figure 2 The scapular assistance test demonstrates the dysfunctional scapula to the patient and examiner by increasing arm elevation. (Color version of figure is available online.)

on the coracoid tip. They would usually be tender to palpation, and even if they are not symptomatic in use, they can be traced to their insertions as taut bands and would create symptoms of soreness and stiffness when the scapulae are manually maximally retracted and the arm is slightly abducted to approximately 40°-50°.[33]

Symptom Alteration (Corrective Maneuvers)

If scapular dyskinesis is demonstrated on the clinical examination of patients with shoulder injury, different types of corrective maneuvers may be employed to determine the effect of the altered motion on symptoms or signs of shoulder injury. The goal of the maneuvers would be to alter or reduce some of the signs or symptoms.

The scapular assistance test (SAT) and scapular retraction test (SRT) are corrective maneuvers that may alter the injury symptoms and provide information about the role of scapular dyskinesis in the total picture of dysfunction that accompanies shoulder injury and needs to be restored.[68,69] The SAT helps evaluate scapular contributions to impingement and rotator cuff strength, and the SRT evaluates contributions to rotator cuff strength and labral symptoms. In the SAT, the examiner applies gentle pressure to assist scapular upward rotation and posterior tilt as the patient elevates the arm (Fig. 2).[68] A positive result occurs when the painful arc of impingement symptoms is relieved and the arc of motion is increased. This test has good test or retest reliability.[70] In the SRT, the examiner grades the supraspinatus muscle strength following standard manual muscle testing procedures or by a hand held dynamometer or evaluates labral symptoms in patients with a positive dynamic labral shear test.[69] The clinician then manually places and stabilizes the scapula in a retracted position. A positive test occurs when the demonstrated supraspinatus strength is increased or when the symptoms of internal impingement in the labral injury are relieved in the retracted position (Fig. 3). The major kinematic result of this test is to increase scapular external rotation and posterior tilt, so a positive test would indicate that rotator cuff strengthening is not necessary, and focus should be on rhomboid strengthening and serratus function in retraction. Although these tests are not capable of diagnosing a specific form of shoulder pathology, a positive SAT or SRT shows that scapular dyskinesis is directly involved in producing the symptoms and indicates the need for inclusion of early scapular rehabilitation exercises to improve scapular control.

Altered GH Rotation

Alterations in GH rotation are consistently found in overhead athletes with DTS and are the factors most highly associated with shoulder pain and injury.[10,23,73] Multiple studies have demonstrated a correlation of altered GH rotation and increased risk of GH injury.[23,74-76] Altered GH rotation creates a shoulder at risk by decreasing the rotation and increasing the amount of translation.[5-7] The most common types of translations are anterior [38] and posterior or superior.[5-7] These translations in the mid and end ranges of motion create shear across the joint and increased loads on the labrum and capsule.[5-7,38] Loss of internal rotation capability also creates "scapular wind-up," scapular protraction in follow-through because of the tight posterior joint structures pulling the scapula with arm motion, creating dyskinesis with its associated problems.

It was originally thought that the altered shoulder rotation was only in internal rotation, and the method of demonstrating this was measuring a decrease in glenohumeral internal rotation (GIR), that a loss of GIR beyond a certain point was considered a deficit (GIRD), and the mechanism of the change was thickening and tightness in the posterior capsule because

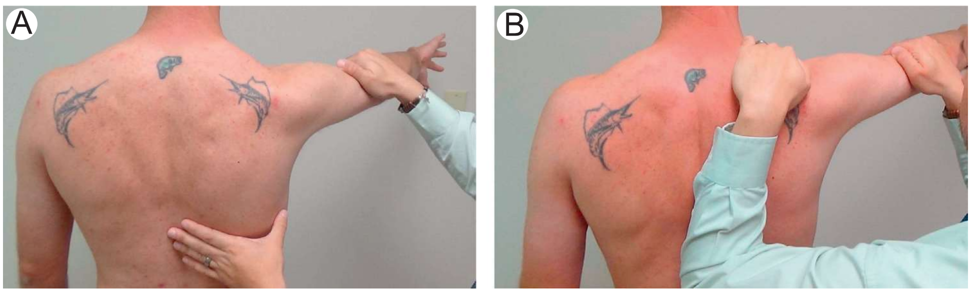

Figure 3 The first component of the scapular retraction test is to manual muscle test the arm in elevation (A) followed by retesting with the application of manual stabilization of the scapula (B). (Color version of figure is available online.)

of repetitive overload.[24,48,49,73,77-81] Laboratory and cadaver studies replicated these alterations and confirmed changes in shoulder kinematics.[5-7] More recent studies have shown that altered rotation, although clearly involved in altered shoulder mechanics and increased risk of shoulder pain, is more complex than can be determined by a single measurement.

First, several studies have shown that the number that represents GIR is dynamic, changing with exposure to an immediate throwing episode or throwing over time.[82-85] Current thought suggests that the "curve of change" (Fig. 4), which represents the joint's response and adaptation, may be a more accurate estimation of the joint's capability. Exact parameters of the optimum "curve of change" are not known[10] but early analysis in asymptomatic pitchers show approximately 4 days to return to baseline early in the season, and 3 days to return to baseline later in the season.[82] Current thought suggests that multiple measurements of GIR using standardized methods[86] should be done over a season.

Second, studies have demonstrated that a significant portion of the asymmetric GIR is because of changes in humeral torsion that develop in young ages, and that this increased retrotorsion, which produces more glenohumeral external rotation (GER) and less GIR, is helpful in achieving the optimum cocking position for high-velocity baseball throwing.[10,76,87-91] The average amount of GIR change from torsion is approximately 12°-18° and should be taken into account when trying to determine GIRD.[87-91] However, the fact that bony changes exist does not account for the 40°-50° GIRD frequently seen in injured athletes, nor does it explain the dynamic alterations in rotation. Current thought suggests that higher amounts of bony retrotorsion may produce less tolerance of soft tissue changes if they develop in throwing, so evaluation of humeral torsion by ultrasound and closer observation for soft tissue changes in athletes with greater than 15° asymmetry may be indicated.

Third, studies have shown that the soft tissue adaptations, especially those seen after acute throwing episodes, may be related to changes in muscle properties. The pinnation pattern of the rotator cuff muscle fibers is more suited to small changes in length than the faster and longer length changes in throwing[92] and adaptive stiffness, called thixotropy, that may decrease the flexibility of the muscle and change the joint rotation.[93-96] This effect is heightened when muscles have decreased strength, a condition demonstrated in throwers. A pilot study on conditioning that emphasized eccentric endurance for the posterior shoulder muscles produced less change in GIR,[97] and suggested that conditioning for both strength and flexibility in the posterior soft tissues may produce more optimum kinematics.

Fourth, recent studies have shown that GER can also be dynamically altered in response to throwing.[76,82] GER is a key factor in optimal cocking. Data suggest that if the dominant arm shows less than 5° greater GER than the nondominant arm, then there is increased risk of injury.[76] Also, early findings from our center show that forearm position can affect GER. A pronated forearm, which is the required forearm position that occurs in full cocking, increases tension in the biceps. Measuring GER with the forearm in pronation often demonstrates 6°-10° less GER than in the traditional neutral forearm position, especially in symptomatic players and in players who have had surgery. Current thought suggests that the lessened GER in the functional position (pronated forearm) would require more shoulder horizontal abduction, which can increase the internal impingement to achieve maximal cocking. Clinical evaluation should include multiple evaluations using standardized methods and include both measurements of forearm pronated and forearm neutral rotation.

Finally, most current thought suggests that the concept of the total range of motion (TROM) is the most unifying concept for function and injury risk.[23,76,80] This offers a larger context to understand how altered motion can affect kinematics and place the shoulder at risk, and it would probably be the best estimation of functionally significant motion. TROM is a more sensitive indicator of joint rotational capability. Latest studies show a higher association of asymmetrical deficits in TROM (TROMD) than GIRD with shoulder injury, and at smaller absolute numbers (8°).[23] Alterations in GIR may constitute the largest part of TROMD, but GER, especially pronated GER,

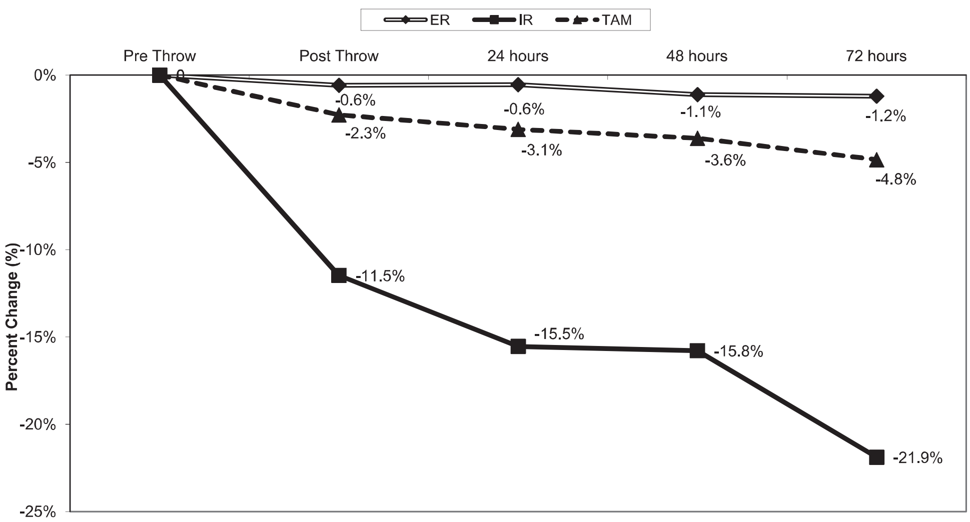

Figure 4 A depiction of range of motion alterations occurring over a 3-day period following an acute throwing episode.

should also be closely evaluated. TROM, such as GIR and GER, needs to be evaluated multiple times, using standardized methods to measure its dynamic character.

Conclusions and Recommendations

Optimum shoulder joint function is dependent upon a complex sequence of motions and positions throughout the entire kinetic chain. In this closed system of force production, alterations in 1 segment of the chain can create alterations in motion, loads, or forces in other segments. Both alterations of scapular static position and dynamic motion, and alterations in GH TROM have been identified and associated with shoulder injury. Neither are probably causative of injury by themselves, but are impairments of optimum function, capable of altering shoulder motions and loads, and should be considered contributors to the shoulder at risk of injury. Scapular position and motion should be assessed as described for every overhead athlete and classified as yes (dyskinesis present) or no (dyskinesis no present). Scapular-based treatment can then be prescribed to correct the dyskinesis for the athlete.

TROM and its component parts GIR and GER should be frequently assessed by using the standardized and reliable methods described. If a single measurement is taken, it is best to do a baseline measurement before any throwing activity. Current recommendations for interventions are side-to-side TROMD $> 8^\circ$, side-to-side GIRD $> 20^\circ$, and side-to-side GER$< 5^\circ$. Multiple rehabilitation protocols have been shown to improve rotation, but protocols that combine horizontal adduction and GIR or GER have shown the best results.[10,98,99]

Summary

The shoulder at risk exists. All the factors responsible for increasing risk are not known. Continuing to adhere to known biomechanics, researchers and clinicians can continue to identify and develop interventions to improve the shoulder's capability of responding to the high demands of the overhead throwing motion.

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