PM R 8 (2016) S69-S77

www.pmrjournal.org

Advanced Sports Medicine Concepts and Controversies

# The Kinetic Chain Revisited: New Concepts on Throwing Mechanics and Injury

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## Abstract

The overhead throwing motion is a complex activity that is achieved through activation of the kinetic chain. The kinetic chain refers to the linkage of multiple segments of the body that allows for transfer of forces and motion. The lower extremities and core provide a base of support, generating energy that is transferred eventually through the throwing arm and hand, resulting in release of the ball. The kinetic chain requires optimal anatomy, physiology, and mechanics and is involved in all 6 phases of overhead throwing: windup, stride, arm cocking, acceleration, deceleration, and follow-through. Breaks or deficits in the kinetic chain can lead to injury or decreased performance. Through an understanding of the mechanics and pathomechanics seen in each phase of throwing, the clinician can better evaluate and screen for potential kinetic chain deficits in the overhead throwing athlete. The purpose of this article is to review the biomechanics of the overhead throwing motion, the role of the kinetic chain in throwing, and the clinical evaluation and management of abnormal throwing mechanics and related injuries.

## Introduction

The overhead throwing motion is a complex activity that involves the entire body to achieve accuracy and velocity [1,2]. This activity is accomplished through activation of the *kinetic chain*, which refers to the mechanical linkages of body segments that allows for the sequential transfer of forces and motions when performing a task such as throwing [3,4]. The kinetic chain has been studied with regard to its role in the normal overhead throwing motion and its impact on injury and decreased performance [1-6]. The throwing motion is a fluid, continuous movement that starts with the lower extremities and core, which provides a base of support and helps generate kinetic energy that translates through the throwing arm, eventually culminating with the ball release from the hands and fingers. An efficient and effective throwing motion requires optimized anatomy, physiology, and mechanics in all of the segments of the kinetic chain. Accordingly, deficits or "breaks" in the kinetic chain can lead to injury or impaired throwing performance. Several studies have investigated shoulder injuries in the overhead throwing athlete, addressing the biomechanics and role of the kinetic chain in injury and training principles for the overhead throwing athlete [6-9].

The purpose of this article is to review the biomechanics of the overhead throwing motion, the role of the kinetic chain in throwing, and the clinical evaluation and management of abnormal throwing mechanics and related injuries. The goal is also to provide the clinician with a structured evaluation and screening tool that assesses potential deficits in the kinetic chain as it pertains to throwing motion.

## Background

### *Throwing and the Kinetic Chain*

The overhead throwing motion traditionally has been divided into 6 phases that primarily focus on upper extremity function: windup, stride, arm cocking, acceleration, deceleration, and follow-through (Figure 1) [2,5,10]. The kinetic chain temporarily links multiple body segments during the phases of throwing motion, including the feet, which provide contact with the ground, maximize the ground reaction force, and create a stable proximal base for distal arm mobility [4]. In addition, maximizing force development in the large muscles of the core and legs produces more than 51%-55% of the kinetic energy that is transferred to the hand [3,5]. The thoracolumbar fascia is involved in the kinetic

http://dx.doi.org/10.1016/j.pmrj.2015.11.015

**Figure 1.** Six phases of throwing. (A) Windup. (B) Stride. (C) Arm cocking. (D) Acceleration. (E) Deceleration. (F) Follow-through.

chain during throwing activities and connects the lower limbs through the gluteus maximus muscle to the upper limbs through the latissimus dorsi. It covers the deep back and trunk muscles, including multifidi, and has attachments to the internal oblique and transversus abdominis muscles [4,11].

An efficient kinetic chain requires optimal anatomy, physiology (that includes muscle flexibility, strength, and task-specific motor patterns), and mechanics throughout all of the body segments involved [3]. Breakdown in the kinetic chain from factors such as variation in motor control, inadequate muscle strength, flexibility and endurance, joint injury, and improper muscle activation patterns can lead to impaired function, performance, and injury [5,6]. A "catch-up" phenomenon has been described in which breaks in the kinetic chain alter forces in distal segments, leading to pain and possible injury [3,12].

For the disabled throwing shoulder, common sites of pathologic deficits include the core, legs, and the shoulder, which includes the scapula [3]. The scapula plays a pivotal role in the throwing motion. Scapular movements during throwing include retraction, upward rotation, posterior tilt, and controlled internal and external rotation. These scapular movements assist with glenohumeral stability [1,3,13]. The shoulder serves as a funnel to transmit forces from the core and trunk to the hand. To maximize shoulder function in the kinetic chain, optimum glenohumeral kinematics must be present to create concavity/compression and stabilize the joint throughout the entire range of motion. Some of the requirements for functional stability include the alignment of the humerus and glenoid within ±30° angulation, a stable scapular base, coordinated contraction of rotator cuff and other shoulder musculature, and labral integrity [3,5]. The arm and hand provide a rapidly moving delivery mechanism of force to the ball [3,13].

In assessing the kinetic chain as it pertains to the baseball pitching motion, 8 nodes or key progressive positions and motions have been described to achieve the overhead throwing task most efficiently. These positions include trunk control over the stance (back) leg, hand on top of the ball in the arm-cocking phase, stride (front) leg directed toward home plate, control of lumbar lordosis in acceleration, hips facing home plate, arm-cocking—scapular retraction/arm horizontal abduction/shoulder external rotation, high elbow above shoulder, and long axis rotation at ball release [3]. These nodes decrease the degrees of freedom in the kinetic chain to achieve maximal torque with minimal development of force [3,5].

In the following sections we will review the normal motions and actions in the 6 phases of throwing and discuss the pitching nodes in the context of the phases. We will also identify the specific deficits and pathomechanics that can occur in each phase and the resulting impact on the kinetic chain, on the potential for injury, and on throwing performance (Table 1).

## Phases of Throwing

### *Phase One: Windup*

#### *Normal Biomechanics*

The first phase, the windup, starts with the thrower in dual leg stance (Figure 1A). The thrower then transfers weight onto the back, stance leg. The trunk and upper body then rotate 90°, and the stride leg is elevated and flexed [2,10]. At the end of the wind-up phase, the thrower should be in a balanced position on the single stance leg [2]. Maintaining balance on the stance leg requires isometric contraction of the stance leg hip abductors to keep a level pelvis, isometric contraction of the quadriceps to maintain knee flexion, and eccentric and isometric contraction of hip extensors to control and maintain hip flexion [2]. The strength of these lower extremity muscle groups helps create a stable base for the distal components of the kinetic chain. The thrower's center of gravity should also be maintained over the stance leg [6].

#### *Pathomechanics*

Weakness of the stance leg hip abductors and knee extensors produces an unstable base of support for the thrower during the windup phase and can lead to pain or injury in these distal segments through the previously mentioned "catch-up" phenomenon [2]. Decreased hip abduction strength has been associated with increased shoulder workload and posterior superior labral tears in overhead throwing athletes [3,13]. Furthermore, overhead throwing athletes with inadequate knee flexion have been reported to have higher loads in shoulder horizontal adduction and rotation and valgus load at the elbow [3]. Poor single-leg balance on the stance leg, impaired trunk control, and premature forward movement also can disrupt the kinetic chain and lead to increased forces on the distal kinetic chain, promoting further risk of injury [6,14].

### *Phase 2: Stride*

#### *Normal Biomechanics*

The second phase is the stride phase, which starts when the hands separate and ends with the stride foot striking the ground (Figure 1B) [2,10]. During the initial part of this phase, the thrower's center of gravity is lowered with contraction of the stance leg hip flexors [2]. The stride leg also extends toward the target. Hip abduction of the stance leg helps initiate forward motion, followed by knee and hip extension of the stance leg [2]. Contraction of the stance leg gluteus maximus provides stability of the pelvis and trunk [6]. The stride leg hip externally rotates while the stance leg hip internally rotates [2]. The torso uncoils and rotates toward the target during this phase [2].

In the upper extremities, the throwing shoulder initiates external rotation and horizontal abduction, and the scapula is brought into protraction, forward tilt, and lateral rotation by the serratus anterior and upper trapezius muscles [2]. This shoulder and scapular positioning prepares the throwing arm for the next phases of throwing. This phase ends when the stride foot contacts the ground. This foot should be positioned toward the target, and the stride leg, stance leg, and target should all be in line [2,3].

#### *Pathomechanics*

During the stride phase, hip internal rotation of the stance leg is important for transfer of energy to the distal segments of the kinetic chain. If restrictions or deficits are present in hip internal rotation in the stance leg, this may lead to early forward rotation of the pelvis and subsequent increased stress on the distal kinetic chain such as the shoulder and elbow [2,10]. Restrictions in stride leg hip external rotation may also influence the kinetic chain because of the influence on stride foot placement [14]. Stride foot positions that close the body cause the athlete to throw across the body and can affect performance and accuracy. Increased stress is also placed on hip and oblique musculature [3,14]. Stride foot positions that open the body can also cause the athlete to throw outside of the target area, which increases the load on abdominal and anterior shoulder muscles and valgus stress on the throwing elbow [3,14].

### *Phase 3: Arm Cocking*

#### *Normal Biomechanics*

The arm-cocking phase starts at the end of the stride phase when the stride foot contacts the ground and ends when the throwing shoulder is at maximal external rotation (Figure 1C) [2,5,10]. The quadriceps in the stride leg contract to decelerate the flexed knee, stabilize the stride leg, and provide a stable base [2]. The pelvis and trunk then rotate toward the target with

**Table 1**
Phases of throwing and the kinetic chain

| Phase | Required Motions/Normal Mechanics | Function | Deficits/Pathomechanics | Evaluation |
|---|---|---|---|---|
| Phase 1: windup (Figure 1A) | Stance leg:<br>Hip abduction, extension<br>Knee flexion (isometric knee extensor contraction) | Provides a stable base for the kinetic chain | Weakness in hip abductors, extensors and knee<br>Unstable base<br>"Catch-up" phenomenon<br>Potential injury in distal kinetic chain<br>Overload of lower extremity muscles to stabilize unstable balance<br>Premature forward motion, poor balance<br>Increase forces on distal kinetic chain | Stance leg:<br>Single leg balance (standing, partial squat)<br>Hip abduction strength (side lying, single leg stance)<br>Hip extensor strength (standing, prone)<br>Quadriceps strength |
| Phase 2: stride (Figure 1B) | Stance leg:<br>Hip abduction, extension<br>Knee extension<br>Hip internal rotation<br>Stride leg:<br>Hip external rotation<br>Foot positioned toward target<br>Shoulder:<br>Shoulder external rotation, abduction<br>Scapular protraction, forward tilt, lateral rotation | Provide stable base for kinetic chain<br>Prepares the throwing arm for the next phases of throwing | Hip and knee weakness: unstable base<br>Hip internal rotation deficits<br>Premature opening up or forward pelvic rotation<br>Increased demand on distal kinetic chain<br>Hip external range deficits → Altered foot positioning<br>Foot positions that close the body increase load on obliques, hip<br>Foot positions that open the body increase load on abdominals, shoulder, medial elbow | Stance leg:<br>Single leg balance and hip/knee strength<br>Hip internal rotation ROM<br>Stride leg:<br>Hip external rotation ROM<br>Foot positioning of stride leg<br>Shoulder:<br>Glenohumeral ROM<br>Scapular dyskinesis evaluation |
| Phase 3: arm cocking (Figure 1C) | Stride leg:<br>Knee extension | Decelerate flexed knee (eccentric)<br>Stabilize stride leg (isometric)<br>Provide stable base | Weakness or tightness of knee extensors:<br>Decreased stability<br>Impaired kinetic chain energy transfer distally<br>Loss of velocity and accuracy<br>Overuse injuries (shoulder, elbow) | Quadriceps strength |
| | Trunk:<br>Pelvis rotation toward target<br>Lumbar spine hyperextension<br>Upper torso rotation | Eccentric control of abdominal obliques to prevent hyperextension | Early trunk rotation<br>Increase valgus strain on elbow<br>Hyperextension of lumbar spine | Timing of trunk rotation<br>Trunk flexibility |
| | Throwing arm:<br>Elbow flexion<br>Shoulder external rotation<br>Shoulder abduction to 90°<br>Scapular retraction, lateral rotation, posterior tilt<br>Hand on top of ball | Elbow and hand lag behind shoulder<br>Rotator cuff activation provides stability to glenohumeral joint<br>Maintain subacromial space<br>Avoid impingement | GIRD >18°-20°<br>Risk of shoulder, elbow injury<br>Increased glenohumeral external rotation<br>Risk of SLAP tears, impingement, rotator cuff tears<br>Increased valgus elbow strain<br>Scapular dyskinesis → external impingement, internal impingement, decreased rotator cuff strength, anterior capsular strain<br>Decreased elbow flexion → increased valgus elbow strain<br>Hand is under or on the side of the ball → increased valgus elbow strain | Glenohumeral ROM<br>Elbow ROM<br>Scapular dyskinesis<br>Hand positioning |
| Phase 4: acceleration (Figure 1D) | Throwing arm:<br>Elbow extension<br>Shoulder internal rotation<br>Shoulder abduction to 90°<br>Scapular protraction<br>Trunk:<br>Forward flexion | Lag between elbow extension and shoulder internal rotation to decrease rotational resistance along longitudinal axis<br>Stable base of support | If throwing elbow is dropped below 90° of abduction<br>Increased valgus load on the elbow<br>Hyperlordosis or back extension<br>Increased load on the abdominals<br>Creates a "slow arm"<br>Increased compression loads at the shoulder | Positioning of elbow<br>Scapular dyskinesis<br>Eccentric and concentric control of lumbar motion in standing position |

| | | | | |
|---|---|---|---|---|
| | Stride leg:<br>Hip flexion, knee extension | | | |
| Phase 5: deceleration (Figure 1E) | Arm/shoulder:<br>Arm deceleration<br>Shoulder internal rotation deceleration<br>Elbow extension deceleration<br>Scapula returns to anterior tilted position | Decelerate throwing arm<br>Counterbalance large internal rotation torque<br>Rotator cuff contraction, posterior capsule limits excessive anterior humeral translation | Most overuse injuries of the posterior arm or trunk occur in this phase or at follow-through<br>Energy must be safely dissipated | Rotator cuff strength<br>Scapular dyskinesis |
| Phase 6: follow-through (Figure 1F) | Trunk deceleration<br>Shoulder deceleration<br>Scapular deceleration<br>Elbow deceleration | Stride leg stabilizes and absorbs forces | Most overuse injuries of the posterior arm or trunk occur in this phase or the late deceleration phase<br>Energy must be safely dissipated | Lumbar flexion<br>Scapular dyskinesis<br>Shoulder horizontal adduction ROM |

GIRD = glenohumeral internal rotation deficit; ROM = range of motion; SLAP = superior labrum anterior to posterior.
The concept of this table was adapted from Kibler WB, Wilkes T, Sciascia A. Mechanics and pathomechanics in the overhead athlete. Clin Sports Med 2013;32:637-651.

subsequent lumbar spine hyperextension and rotation of the upper torso [2]. Eccentric contraction of the abdominal obliques prevent excess hyperextension of the lumbar spine [6]. Stability of the pelvis and hip is controlled by contraction of the gluteal muscles [14].

In the upper extremities, the throwing arm is externally rotating at the shoulder and flexing at the elbow. The throwing shoulder progresses toward maximal external rotation as the shoulder reaches 90° of abduction [2]. The elbow and hand lag behind the trunk and shoulder during this phase. When the shoulder is at maximal abduction and external rotation, the scapula is positioned in maximal retraction, lateral rotation, and posterior tilt [2]. This positioning of the scapula is important to maintain the subacromial space and prevent impingement during the throwing motion [2].

Forces and stress on the shoulder, elbow, trunk, and lower extremities are highest during the arm-cocking and acceleration phases [5]. Repetitive overhead throwing motions result in adaptive changes in the throwing shoulder, with an increase in glenohumeral external rotation and a decrease in glenohumeral internal rotation compared with the nonthrowing shoulder. However, the total arc of rotation remains unchanged [2]. The highest forces on the shoulder and elbow are seen during the transition from the late arm-cocking phase to the early acceleration phase, when there is a sudden transition from external rotation of the shoulder to internal rotation, which is the period of highest injury risk [5]. For hand positioning, the normal mechanics involve the hand on top of the ball, with the forearm in pronation [3,15].

### *Pathomechanics*

Weakness or tightness of the stride leg knee extensors can alter knee motion and produce an unstable base of support [2,3], which can result in decreased throwing performance, impaired force generation, and overuse injuries in the distal segments of the kinetic chain, particularly the shoulder and elbow [2]. In addition, early trunk rotation has been shown to increased valgus torque on the throwing elbow [2,3]. Weakness of the abdominal oblique muscles can lead to hyperextension of the lumbar spine.

Glenohumeral internal rotation deficit greater than 18°-20° increases the risk of injury at the shoulder and the elbow [2,3]. Increased glenohumeral external rotation has also been associated with superior labrum anterior to posterior tears, rotator cuff impingement, and tears and increased valgus stress on the elbow [2]. Hyperangulation of the humerus in relation to the glenoid can cause an increased load to be placed on the anterior shoulder with resultant internal impingement [3]. Alterations in positioning or dynamic motion of the scapula, known as scapular dyskinesis, can be due to muscle weakness, inflexibility, or imbalance and has been associated with 67%-100% of shoulder injuries

[3,13]. Scapular dyskinesis can lead to external impingement, internal impingement, decreased rotator cuff strength, and increased anterior capsular strain [3]. In terms of hand positioning, if the hand is under or on the side of the ball, an increased valgus strain can be placed on the elbow [3].

### *Phase 4: Acceleration*

*Normal Biomechanics*

The fourth phase, the acceleration phase, begins when the shoulder is at maximal external rotation and ends when the ball leaves the hand (Figure 1D). During this phase, the trunk continues to rotate and tilt, acting to transfer energy through the upper extremity [6]. The trunk moves from a hyperextended position to a forward flexed position, and there should be a controlled lordosis [2,3]. The abdominal obliques, rectus abdominis, and lumbar paraspinal musculature of the non-throwing side appear to have greater activity compared with the throwing side during acceleration and are important in accentuating pelvic and truncal rotation [6]. In addition, contraction of the rectus femoris contributes to hip flexion of the stride leg and knee extension, which provides a stable anterior base [6]. An increase in forward truncal tilt allows the throwing upper extremity to accelerate through a larger distance, increasing the force that is transferred through the ball [6].

The serratus anterior contributes to scapular protraction and helps provide a stable base for horizontal adduction and internal rotation of the humerus [6]. The subscapularis, pectoralis major, and latissimus dorsi reach maximal activity during this phase, causing the large amount of internal rotation of the humerus [6]. At the start of this phase, the elbow initially flexes from 90°-120° and then rapidly extends to just prior to release of the ball [6]. The elbow extension results from a combination of the force generated by rotation of the trunk and contraction of the triceps [6]. A short delay between elbow extension and the start of shoulder internal rotation decreases rotational resistance of the arm and helps increase ball velocity [2,5,10]. The optimal position of the throwing arm is with a high elbow, at 90° of shoulder abduction, to minimize impingement and maximize strength [2,3]. Wrist flexion to neutral and radioulnar pronation assist in release of the ball [6].

*Pathomechanics*

Hyperlordosis or back extension places increased load on the abdominals and creates a "slow arm" in which the arm is behind the body with increased abduction and external rotation at the shoulder, which results in increased compression loads at the shoulder [13]. Hyperlordosis also loads the posterior elements of the spine. If this load is excessive, the player is at risk for the development of spondylolysis [16]. If the throwing elbow is dropped below 90° of abduction, this position can place an increased valgus load on the elbow [3].

### *Phase 5: Deceleration*

*Normal Biomechanics*

The fifth phase, the deceleration phase, starts when the ball leaves the hand and ends when the shoulder is at maximal internal rotation (Figure 1E). The stride leg absorbs some of the forces that are produced during acceleration because it is planted during this phase. After the ball release, the arm continues to extend at the elbow and internally rotate at the shoulder, and the arm adducts across the body to 35° [6]. This phase causes the greatest amount of glenohumeral joint loading during throwing, with inferior shear forces, increased compressive forces, and adduction torques [2,6]. These large forces are dissipated by the posterior shoulder soft tissue musculature, including the teres minor, infraspinatus, and posterior deltoid [6]. Rotator cuff contraction and the posterior capsule help limit excessive anterior translation of the humerus [2]. After release of the ball, the throwing arm is directed toward home plate, the elbow is flexed to 25°, and the arm is abducted an average of 93° while horizontally adducted 6°. Eccentric contraction of the elbow flexors, the biceps, and the brachialis muscles decelerate the rapidly extending elbow and pronating forearm [2,6]. In addition, the trapezius, serratus anterior, and rhomboids help decelerate the shoulder girdle and stabilize the scapula as it returns from an upward position to an anteriorly tilted position [2,6].

*Pathomechanics*

Most overuse injuries in the posterior arm or trunk occur during the deceleration and follow-through phases because of the large amount of energy that must be dissipated during these phases [2]. A greater amount of force is needed to decelerate the throwing arm in the deceleration phase than in the follow-through phase [2]. The large eccentric contractile needs of the musculature of the posterior shoulder are likely the cause of the posterior capsule and soft tissue reaction seen in pitchers with glenohumeral internal rotation deficit [6]. Pathologic conditions that are associated with this phase include tears of the superior labrum (ie, superior labrum anterior to posterior tears), along with biceps, brachialis, and teres minor injuries [17].

### *Phase 6: Follow-Through*

*Normal Biomechanics*

The sixth phase is the follow-through phase, during which weight is transferred to the stride leg. The body moves forward with the throwing arm until motion ceases (Figure 1F) [6]. The trunk decelerates and is flexed over the stride leg, which is extended at the knee. Horizontal shoulder adduction continues to 60°, and this phase ends with the pitcher in a fielding position [6]. The stride leg provides stability and absorbs the force of the throw, and the stance leg then is brought to the ground with the knee and hip flexed [2]. The throwing arm also continues to decelerate during this phase, with different muscle groups eccentrically contracting to decelerate the shoulder, scapula, and elbow [2,5,10].

#### *Pathomechanics*

Overall, the energy required to decelerate the throwing arm in the follow-through phase is less than in the deceleration phase of throwing [2]. However, both phases are associated with overuse injuries of the posterior arm and trunk as a result of the large amount of energy that must be dissipated safely from the throwing motion [2]. Abruptly stopping arm motion in this phase will prevent energy dissipation and causes the forces created during the throwing motion to be absorbed by the shoulder [18].

## Evaluation

The clinical evaluation of the throwing motion can be challenging because of the multisegment and dynamic nature of the activity. As discussed previously, the normal biomechanics of each phase of throwing requires optimal strength, flexibility, and anatomy of different components of the kinetic chain. Pathomechanics and deficits within the kinetic chain can increase the risk of injuries and lead to poor performance in the overhead throwing athlete. Identification of these areas through examination of strength, flexibility, and direct observation of throwing mechanics can help screen athletes for potential deficits in the kinetic chain and can also help target an appropriate and effective treatment and rehabilitation plan for the athlete. In the following section we will discuss specific components of the clinical evaluation of the throwing motion and the associated phases of throwing (Table 1).

### *Lower Extremity Assessment*

The lower extremities play an important role in the throwing motion. The motions and strength of both legs help provide a stable base for the kinetic chain and the remainder of the throwing motion. Single-leg balance on the stance leg should be evaluated in stance and in partial squat, because poor balance in the windup phase leading to premature forward motion can lead to disruption of the kinetic chain. Formal testing of stance leg hip strength should be performed, with evaluation of hip abduction strength in single-leg stance to assess for the presence of a positive Trendelenburg sign, as well as in the side-lying position [19], and evaluation of hip extension strength in standing and prone positioning. Hip range of motion should be evaluated in both stance and stride legs to identify any restrictions in hip internal or external rotation. Knee extensor strength and flexibility should also be evaluated because they are important for providing stability in the stance leg during the windup and stride phases, and in the stride leg during the arm-cocking phase. Dynamically, foot positioning of the stride leg at the termination of the stride phase of throwing can be assessed through direct clinical observation.

### *Core and Trunk Assessment*

Trunk flexibility and range of motion should be evaluated because of the importance of trunk movement during the later phases of throwing. Eccentric and concentric control of lumbar motion should be evaluated in the standing position as the trunk moves from hyperextension in the arm-cocking phase to a forward flexed position in the acceleration phase to trunk deceleration. Timing of trunk rotation during the arm-cocking phase can be assessed through direct clinical observation.

### *Scapular Assessment*

The scapula plays a key role in shoulder function, with abnormalities termed *dyskinesis* commonly seen in the disabled throwing shoulder. Scapular dyskinesis should be evaluated in the throwing athlete, particularly to identify for deficits in the stride, arm-cocking, and deceleration phases. To evaluate for the presence or absence of scapular dyskinesis and aid in the development of a rehabilitation regimen, a clinical observation method has been described. This method has been correlated with biomechanically determined scapular positions and motions in symptomatic patients. The first part of this protocol is an evaluation of inflexibilities, including those of the pectoralis minor and glenohumeral internal rotation [20,21]. The degree of tightness of the pectoralis minor can be ascertained by having the patient stand against the wall and measuring the distance from the wall to the anterior acromial tip [22]. This measurement can be performed with a “double square” device, which consists of a 12-inch combination square with a second square/level added in an inverted position. With the patient’s buttocks or back touching the wall, the distance is measured from the wall to the anterior tip of the acromion process [23]. Measurements should be taken bilaterally to determine whether a notable difference exists between the symptomatic and asymptomatic shoulder, with a side-to-side difference of greater than 3 cm considered abnormal. Direct measurement can be performed by measuring the distance between the fourth rib at its sternal articulation and the coracoid process in a standing position [20].

The scapular resting position and dynamic motion are then assessed by observing the scapula as the arms move from a neutral position to 180° of forward flexion and back to a neutral position [24]. If the medial border of the scapula is prominent during this test, particularly while lowering the arms, then dyskinesis is present. The final aspect of this part of the assessment involves corrective maneuvers. External impingement symptoms can be decreased by the scapular assistance test, in which the examiner provides gentle pressure to assist scapular upward rotation and posterior tilt as the patient elevates the arm. The test is considered to be positive when the painful arc of impingement symptoms are relieved and the motion arc is increased.

In addition, during the scapular retraction and reposition tests, the examiner externally rotates and posteriorly tilts the scapula, with an associated decrease in internal impingement symptoms in persons with labral injuries [25,26].

### *Glenohumeral Rotation Assessment*

Changes in glenohumeral rotation have been shown to be a key component of normal and abnormal throwing mechanics. Glenohumeral rotation should be evaluated for deficits, which can lead to abnormal stresses during the stride and arm-cocking phases of throwing. The majority of studies evaluate glenohumeral rotation with the arm at 90° of abduction in the scapula plane and using a bubble goniometer for measurement [27,28]. The method described here has been shown to have a test-retest reliability of 0.96 [27] and is sensitive to a meaningful change of 3°. For ideal evaluation, the athlete is placed in a supine position on a level surface [1]. One examiner should stand at the head of the athlete and stabilize the athlete's scapula by providing a posteriorly directed force against the anterior shoulder in the region of the coracoid process. The other examiner should passively flex the athlete's elbow to 90°, abduct the shoulder to 90°, and place a bolster posterior to the athlete's humerus to position the humerus in the scapular plane. The examiner should position the goniometer appropriately, with the fulcrum at the olecranon process of the elbow, the stationary arm perpendicular to the table, and the moving arm in line with the styloid process of the ulna. The humerus is then passively internally rotated until "tightness" is encountered. The term "tightness" refers to a point where no additional glenohumeral motion occurs. The same process should be followed to assess external rotation. Total range of motion is calculated by adding the glenohumeral internal rotation and external rotation ranges of motion. This process should be repeated for the nonthrowing shoulder, and the difference in external and internal rotation and total range of motion should be compared from side to side, with a difference of greater than 5° considered abnormal [29].

## Rehabilitation Principles

Once the clinical evaluation of the overhead throwing motion and kinetic chain is completed, treatment of throwing injuries should focus on addressing any kinetic chain deficits or altered throwing biomechanics, improving joint stability, and optimizing anatomy [3]. Based on the specific node where the pathomechanics are identified, the rehabilitation may involve improving and optimizing hip range of motion, hip and leg strength, core stability and strength, scapular control, shoulder range of motion and strength, and restoration of glenohumeral rotation. Rehabilitation can help reduce the need for surgery [1,3].

Rehabilitation of the disabled throwing shoulder has been discussed previously in the literature and is thoroughly described in another article in this supplement. After evaluation of the overhead throwing mechanics and kinetic chain, as previously discussed, the 3-phase rehabilitation program addresses the kinetic chain, shoulder mobility, and shoulder strengthening. For the kinetic chain, deficits in motion of the spine, hip, and lower extremity should be addressed. Core and lower extremity strengthening and stability should also be a focus of the rehabilitation program. Dynamic core exercises can help improve throwing performance and power [1]. Posterior capsule stretches such as the cross-body and sleeper stretches can help improve glenohumeral internal rotation deficit. Additional stretching can be used to address tight anterior shoulder structures (eg, the pectoralis minor) and correct flexibility imbalances [1]. For athletes with shoulder strength deficits, initial treatment should focus on improving scapular muscular control and proximal stability, followed by strengthening of weak shoulder muscles and functional exercises [1].

Surgical repair should be reserved for throwers who have not responded to appropriate rehabilitation and continue to have pain and difficulty with throwing. The goal of surgery should be to improve the anatomy of the shoulder to allow for additional rehabilitation, and it should be considered a procedure to salvage an athlete's career [1].

## Conclusion

Understanding the proper mechanics of the overhead throwing motion and the role of the kinetic chain in throwing is important when evaluating the overhead throwing athlete. The kinetic chain requires optimal anatomy, physiology, and mechanics to efficiently transfer energy from the legs and core to the arm and hand. When evaluating an overhead throwing athlete, observation of overhead throwing mechanics and examination of the kinetic chain and shoulder should be performed. Screening should include evaluation of leg stability and strength, hip range of motion, core stability, and flexibility as previously outlined and shown in Table 1. A comprehensive shoulder examination should be performed, including glenohumeral range of motion, rotator cuff strength testing, and assessment for scapular dyskinesis. Based on any deficits identified on clinical evaluation, rehabilitation should be initiated to address any altered biomechanics or kinetic chain dysfunction, optimize anatomy, and improve stability of the joints. Surgery should be a last resort for athletes who have not responded to aggressive rehabilitation and continue to have pain or difficulty throwing.

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Disclosure: nothing to disclose

Submitted for publication September 28, 2015; accepted November 21, 2015.