Background: Shoulder complex injuries are common among overhand throwing athletes. These injuries often manifest as a result of habitual sport performance and often lead to time loss injuries. The mechanisms of these injuries are often non-traumatic and theories on how shoulder injuries manifest differ.

Objectives: To describe the proposed mechanisms of commonly reported shoulder injuries as they relate to the phases of the throwing motion.

Major findings: Shoulder injuries commonly involve rotator cuff muscles and tendons, scapulothoracic muscles, glenohumeral joint labrum, proximal humeral epiphysis, glenohumeral joint capsule, biceps muscle and tendon, and subacromial bursa. The injuries found in these tissues and their purported mechanisms of injury during the throw vary.

Conclusions: The late cocking and deceleration phases have been implicated with the largest number of associated pathologies. Multiple injuries were theorized to occur at more than one phase of the throwing motion. Consensus has not been achieved on the provocative events leading to shoulder injury during the throwing motion.

Keywords: Biomechanics, Shoulder, Throwing injury

Introduction

Throwing athletes are prone to upper extremity injuries secondary to repetitive end range movements with high associated torques during sport participation. The dynamics of the throwing motion necessitate athletes to have sufficient range of motion, strength, endurance, and neuromuscular control to dissipate the stresses placed on the body. The upper extremity, in particular the shoulder is the most common injury location in throwing athletes.1–10 Furthermore, severe shoulder injuries are the most likely to limit elite level baseball players’ participation.11 Shoulder injuries in throwers manifest in many tissues including rotator cuff muscles and tendons, scapulothoracic muscles, glenohumeral joint labrum, proximal humeral epiphysis, glenohumeral joint capsule, biceps muscle and tendon, and subacromial bursa, among others. The majority of throwing injuries are not incited by any one incident but through repetitive end-range loading.12 The aim of this narrative review is to describe common shoulder injuries found in baseball players and their theorized mechanisms of injury as they relate to the biomechanics of the throwing motion. This information will assist physical therapists and other sports medicine professionals in injury prevention, rehabilitation, and improvement of athletic performance in throwing athletes.

The throwing motion has been described as a coordinated effort through the legs and trunk resulting in a high velocity and forceful upper extremity action.13 Exploiting this summation of energy yields the ability to throw a baseball with velocities nearing 100 miles/hour but also places large physiological stresses that have the potential to create many injuries. The throwing motion has been described to have five or six phases that are determined by kinematic time points during the throw. The throwing motion (Fig. 1) starts with the wind-up, progresses through early then late cocking, acceleration, and deceleration, and finishes with follow through.4

Reported Injury Mechanisms during Specific Phases of the Throw

Phase 1: the wind-up

The wind-up starts from the initiation of movement. The intention of this phase is to position the body in a way that facilitates the rest of the throw. As such, there is large individual variation in the kinematic pattern and velocity of movement during the wind-up to accommodate differing throwing styles (traditional wind-up or the stretch).14 During this time, weight is
shifted toward the plant (back) leg while the lead leg elevates bringing the knee toward the chest.5 Wind-up transitions into the early cocking phase once the lead knee is at maximum height and the hands separate.4 No prior research has described specific injuries occurring during this period given the relatively slow kinematic velocities and low associated forces.

Phase 2: early cocking
The second phase is known as the cocking phase and is often split into early and late portions. Early and late cocking combined account for nearly 80% of the time required for throwing which equals \(\sim 1500\) milliseconds.14 During early cocking, the trunk rotates toward the side of the throwing arm and the lead leg positions the body toward the target.5 In an attempt to locate the ball posteriorly, the scapula is retracted while the humerus is abducted to near 90° and is horizontally abducting while externally rotating.15 The elbow is flexed to \(\sim 90°\).

Early cocking is the first phase during the throw where specific biomechanically related injuries have been reported. Pathological internal (posterior glenoid) impingement has been linked with the early cocking phase.16 Internal impingement is a condition in which the superior aspect of the infraspinatus and/or the posterior aspect of the supraspinatus tendons become mechanically impinged between the humeral head and the posterior superior glenohumeral labrum.17 Internal impingement has been reported to be an expected and normal phenomenon in throwing.18 Only when the impingement leads to pain, inflammation, or damage of the posterior/superior joint tissues (rotator cuff tendons, glenoid labrum, greater tuberosity, or superior glenoid rim) does the condition become pathological. In general, the mechanism of injury is described as arising when the humerus repetitively horizontally abducts beyond the plane of the scapula injuring the implicated tissue(s) (Fig. 2).19,20 This positional fault may be exacerbated by several other factors including faulty scapular kinematics, anterior instability (described later), decreased humeral torsion, and poor throwing mechanics as well.15,21–23

Altered scapular position may predispose the posterior tissues to internal impingement.21 Specifically, deficient scapular external rotation during the cocking phase may predispose internal impingement as the glenoid is positioned more anteriorly.21 This malpositioned scapula creates a more anteriorly oriented scapular plane. In turn, internal impingement may occur as the humerus horizontally abducts posterior to the anteriorly malpositioned scapular plane. Three-dimensional scapular kinematics measured during the throwing motion indicate that maximal scapular external rotation occurs during late cocking lending credence to altered scapular kinematics as a mechanism of injury during this phase.15 Internal impingement has been described to occur in both early and late cocking depending on individual throwing characteristics.19,21,22,24,25 The phase of throwing during which internal impingement occurs will vary based on predisposing factors including scapular kinematics, anterior glenohumeral restraints, and range of motion utilized during the throw. The injurious kinematics involved, however, are similar.

Figure 2 Anatomical depiction of internal impingement. Reprinted from the American Journal of Sports Medicine, 26/3, Riand N, Levigne C, Renaud E, Walch G, Results of Derotational Humeral Osteotomy in Posterosuperior Glenoid Impingement, p. 454, Copyright 1998, with permission from Elsevier.
**Phase 3: late cocking**

As the lead foot makes ground contact, the thrower transitions from early cocking into the late cocking phase. Late cocking places the humerus at its most extreme range of motion and has been reported to exhibit an anterior shear force equal to approximately half the thrower’s body weight. During late cocking, the entire body is moving toward the target location, the torso is extending and rotating away from the throwing side, the scapula retracts, elevates, and externally rotates while the humerus is elevated and externally rotating. The elbow is flexing and the wrist will slightly extend.

The late cocking phase of the throw is associated with assorted injuries secondary to the extreme range of motion of the upper extremity during this time. Superior labrum anterior-to-posterior (SLAP) lesions have been reported to occur during the late cocking phase of the throw via a ‘peel-back mechanism’. An SLAP lesion is a tearing of the superior aspect of the glenohumeral labrum which often includes the proximal insertion of the biceps tendon. The SLAP lesion is theorized to occur via repetitive contraction of the biceps with the humerus positioned in abduction and maximal external rotation as in late cocking. This humeral position creates a posteriorly oriented tensile force through a rotationally torsioned long head of the biceps. The extreme humeral position and corresponding angle of pull combined with the rotation through the proximal bicep tendon is proposed to torsionally stress the superior labrum. This may cause a compromise of the superior labrum or become pathological if the labral attachment has been previously compromised. The peel-back injury mechanism to the superior labrum theory has been supported through cadaveric study.

As skeletally immature throwers attempt to position the humerus into maximal external rotation, the humerus is susceptible to epiphyseal changes. Humeral retro torsion, or posterior twisting of the humeral head on the diaphysis, is a common finding among throwing athletes as the epiphyseal plate is weaker than the supportive ligaments. Humeral retro torsion is associated with alterations in humeral rotation range of motion. Throwers often exhibit increased external rotation and decreased internal rotation at the glenohumeral joint associated with the altered humeral shaft rotation. Similar to internal impingement, humeral retro torsion is thought to be a normal osseous adaptation to repetitive throwing that transpires prior to skeletal maturity. However, humeral retro torsion has also been implicated as a risk factor for shoulder injury.

Proximal humeral epiphysi osis, on the contrary, is a pathologic condition at the proximal humeral epiphysis noted by localized pain and radiographic evidence of epiphyseal widening. This pathological condition has been referred to as: ‘Little Leaguer’s shoulder’, proximal humeral epiphysis, proximal humeral epiphyseolysis, or a rotation stress fracture of the proximal humeral epiphyseal plate. Proximal humeral epiphyseolysis is thought to occur when the rate or frequency of loading into shoulder external rotation (late cocking) causes growth plate damage. Rotational torques measured during throwing in youth baseball players substantiate this injury mechanism. As the arm is placed in the late cocking position, the anterior glenohumeral ligaments are placed under tension. Movements toward terminal humeral horizontal abduction and external rotation place tensile stresses across the anterior ligaments which, over time, can introduce tissue stretching creating increased anterior humeral head shearing. In addition to anterior ligament elongation pathologies of the glenohumeral joint, tearing of the anterior glenoid labrum and glenohumeral instability are also implicated by such attenuation. This decreased stability of the glenohumeral joint has been theorized to create greater potential for impinging the posterior rotator cuff tendons. This may be further exacerbated with fatiguing throwing conditions.

**Phase 4: acceleration**

Acceleration begins when the humerus initiates movement from maximal humeral external rotation into internal rotation and ends with ball release. Acceleration has been reported to occur over 50 milliseconds (2% of the throw) with reported humeral rotational velocities averaging up to 7000/second. It has also been noted that up to 1100 N of distractive force occurs on the humerus during acceleration. Kinematically, the torso laterally bends and rotates away from the throwing side while slightly flexing. The scapula internally rotates and anterior tilts as the humerus moves into horizontal adduction and internal rotation. The elbow continues to extend with wrist flexion and pronation until ball release. At ball release, the lead knee will be extending while planted on the ground. Glenoid labrum fraying has been noted to occur during acceleration if active or passive humeral stabilizers are ineffective. This instability can cause the humeral head to articulate with the labrum as opposed to the glenoid causing an abnormal compressive load with motion and thus labral tearing. The rotator cuff muscles are primarily responsible for resisting the great distractive forces at the glenohumeral joint. Labral fraying could follow if the humeral head is not centered within the glenoid and the compressive forces are repetitively misplaced onto the labrum. The potential for increased contact with the labrum may increase in the presence of abnormal capsuloligamentous laxity (described earlier) or muscle fatigue from repeated throwing.
Phase 5: deceleration

The deceleration phase attempts to dissipate the high velocities of the upper extremity after ball release. The angular deceleration has been reported to occur over 50 milliseconds. Slowing the arm from the high acceleration velocities imposes a distractive force at the shoulder which has been demonstrated to approximate body weight. Subsequently, the deceleration phase of throwing is implicated in the majority of shoulder injuries as the body attempts to slow the arm from exceptionally high rotational velocities following ball release. Kinematically, during deceleration, the lead leg is in unilateral stance and the torso continues to rotate away from the throwing shoulder. The scapula continues to anteriorly tilt while internally and downwardly rotating. The humerus adducts, horizontally adducts, and internally rotates with an elbow nearly full extended and wrist toward end range of motion into flexion. SLAP lesions, which were described above to occur during the late cocking phase, have also been reported to occur via tensile forces during deceleration. The SLAP lesion occurs as the biceps is very active proximally, in stabilizing the humeral head, and distally, attempting to slow elbow extension. Elbow extension velocities and maximal humeral distraction torques occur at the same time interval requiring eccentric biceps contraction to resist proximal and distal loads. This large tensile load, acting through the proximal attachment to the labrum is thought to be an additional mechanism of SLAP tear. Accordingly, tensile injuries to the biceps tendon have been theorized to come about during deceleration. Inflammation and tearing secondary to the large eccentric strain placed on the biceps tendon implicate both the tendon and the superior labrum.

The deceleration phase has also been implicated in tearing of the supraspinatus and infraspinatus. This report, based on surgical data, indicated that the majority of tears were noted in the mid-supraspinatus to the mid-infraspinatus and resulted from tensile failure as these muscles attempted to resist distraction, horizontal adduction, and internal rotation of the humeral head. Supraspinatus and infraspinatus intratendinous articular surface partial thickness tears are also implicated with the large eccentric forces of the rotator cuff during deceleration. This area is reported to be at increased risk of tearing due to the low ultimate stress to failure and hypovascularity relative to the bursal surface of the tendons. Supraspinatus and infraspinatus intrinsic articular surface partial thickness tears are also implicated with the large eccentric forces of the rotator cuff during deceleration.

Phase 6: follow through

The follow through and deceleration phases are separated by maximum humeral internal rotation. Follow through completes the throw cycle and involves extension of the stride knee, continued hip flexion, shoulder adduction and horizontal adduction, elbow flexion, and forearm supination. This time period acts to decrease the loading rate on the involved joints by increasing the time associated with slowing body movements. Follow through of the throw occurs over approximately 300 milliseconds, which equates to ~15% of the total throwing time. Some authors report injuries during follow through; however, these primarily occur during deceleration using the context described above, as these two phases are occasionally not separated.

Conclusion

The intention of this manuscript was to provide an overview of common shoulder injuries found in throwing athletes. The late cocking and deceleration phases have been implicated with the largest number of associated pathologies. This review also attempted to describe these injuries in relationship to the kinematic and kinetic parameters associated with the throwing motion. Many shoulder pathologies have multiple mechanisms resulting in injury.
proposed etiologies during the throwing motion suggesting the need for further research. By understanding the characteristics of the throw and injuries that occur during the respective phases, physical therapists and other sports medicine clinicians will be well suited to assist athletes with shoulder-specific training, injury prevention, and rehabilitation programs.

References