Understanding Shoulder and Elbow Injuries in Baseball

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Abstract

Repetitive overhead throwing exerts significant mechanical stress on the shoulder and elbow joint; this stress can lead to developmental anatomic changes in the young thrower. Asymptomatic pathology in the shoulder and elbow joint is prevalent and, with overuse, can progress to disabling injury. Joint injury occurs as a result of the body's inability to properly coordinate motion segments during the pitching delivery, leading to further structural damage. Identifying and preventing overuse is the key to avoiding injury, particularly in the young pitcher. Injury prevention and rehabilitation should center on optimizing pitching mechanics, core strength, scapular control, and joint range of motion.

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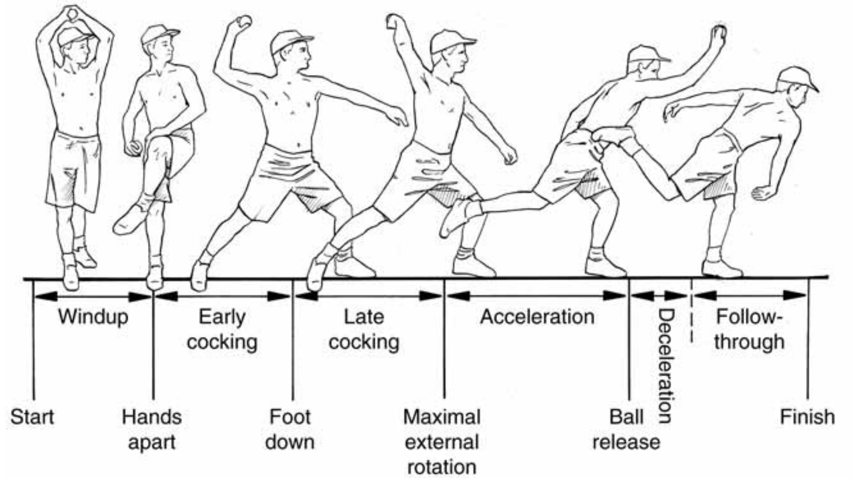
Sports involving repetitive overhead throwing, particularly baseball, create significant clinical challenges for the sports medicine physician. Most of the injuries that occur in professional throwers involve the shoulder and elbow joints.[1] This injury pattern should be of concern, considering the rising popularity of youth athletics in the United States. Nearly 200,000 teams participate annually in Little League Baseball alone. In addition, young athletes participate in numerous other youth, high school, and collegiate baseball leagues. Understanding and properly caring for injuries in the overhead throwing athlete extends beyond orthopaedic sports medicine; it addresses a public health concern. Improving our understanding of pitching biomechanics, developmental and adaptive changes in the upper extremity, and injury mechanisms will allow us to better prevent shoulder and elbow injuries.

Pitching Biomechanics

The baseball pitch serves as the biomechanical model for many overhead throwing motions.[2] The pitching motion is a kinetic chain that derives energy from the lower extremity, transfers that energy through pelvis and trunk rotation, and subsequently releases it through the upper extremity.[3,4] This kinetic chain occurs in six phases, which are divided by reproducible points within the pitching motion; these points include the parting of the hands, contact of the stride foot, maximum external rotation of the throwing arm, and ball release[5] (Figure 1).

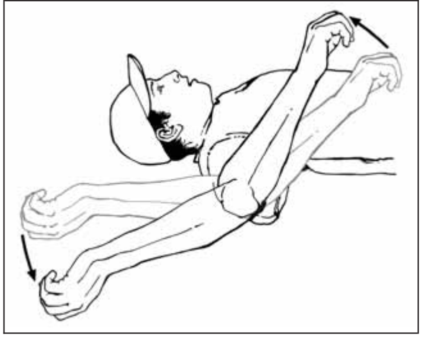
As energy is funneled through the trunk and into the sequentially smaller motion segments of the upper extremity, structures within the shoulder and elbow joint experience tremendous biomechanical stress. Varus torque produced at the elbow during the overhead pitch can approach 65 Nm, while internal rota-

Figure 1



The phases of the baseball pitch. (Adapted with permission from DiGiovine NM, Jobe FW, Pink M, Perry J: An electromyographic analysis of the upper extremity in pitching. *J Shoulder Elbow Surg* 1992;1:15–25.)

Figure 2



The arc of rotation in the thrower's shoulder is examined in the supine position to help stabilize the scapula. The rotational arc is shifted in the direction of external rotation, secondary to developmental humeral retroversion and soft-tissue adaptation.

tion torque at the shoulder approaches 67 Nm; this translates to 300 N of medial shear force at the elbow and 310 N of anterior force at the shoulder joint.[2] Professional pitchers can generate up to 92 Nm of humeral rotation torque; this is greater than the reported torsional strength of the humerus in cadaveric studies.[6] The external rotation stress at the shoulder and valgus stress at the elbow lead to reproducible developmental changes in the upper extremity and, eventually, to injury in many throwers. Despite interest in adjusting pitching biomechanics in the developing thrower with the goal of minimizing joint stress, no data suggest that alterations in mechanics alone can overcome the repetitive joint stress associated with pitching.

Developmental and Adaptive Changes in the Shoulder and Elbow

The repetitive stress placed on joints by pitching alters the developmental anatomy of the upper extremity at an early age. In a study of skeletally immature baseball players (boys aged 8 to 15 years), 55% of asymptomatic and 62% of symptomatic subjects showed radiographic evidence of physeal widening in the dominant shoulder, establishing that anatomic changes can occur early in life and in the absence of symptoms.[7] Change in glenohumeral range of motion in the throwing athlete also begins at an early age, with the greatest change occurring in athletes aged 13 to 14 years.[8] The development of the elbow joint also is affected by the repetitive throwing in competitive youth baseball. Hang et al[9] found that 94% of competitive youth baseball players had radiographic evidence of medial epicondylar apophyseal hypertrophy and that, of the players with physeal separation or fragmentation, nearly half were asymptomatic.

An increase in glenohumeral external rotation and a decrease in glenohumeral internal rotation is evident in the throwing athlete's shoulder by the time the athlete reaches the collegiate level.[8,10] The increased external rotation can average almost 10° and is matched by a compensatory decrease in internal rotation; the asymptomatic thrower, however, generally maintains the total arc of rotation in the shoulder.[8,10,11] This shift in the rotational arc (Figure 2) often is attributed to capsular changes, but much of this change can be explained through developmental osseous adaptation alone.[8,10] Crockett et al[12] quantified increased humeral retroversion in the professional pitcher at an average of 17° in the dominant shoulder compared with the nondominant shoulder; this osseous adaptation explains much of the rotational arc shift in the thrower's shoulder. There also are soft-tissue adaptations in the thrower's shoulder that must be noted.

Recent clinical and cadaveric studies have quantified capsular laxity as it pertains to rotational and translational motion in the shoulder. Sethi et al[10] recently reported increased capsular laxity in the dominant shoulder compared with the nondominant shoulder in pitchers, as evidenced by increased anteroposterior translation of >3 mm. Although Borsa et al[13] found no side-to-side difference in anterior and posterior translation in asymptomatic professional pitchers, they quantified the direction of laxity and found that posterior translation was consistently greater than anterior translation in the thrower's shoulder. This increased posterior laxity contradicts the idea that posterior capsular contracture is the primary cause of decreased internal rotation in the asymptomatic thrower. In their cadaveric study, Mihata et al[14] suggest that a progressive, nondestructive external rotation stretch of the shoulder capsule leads to increased glenohumeral translation. Thus, the current literature indicates that, in the asymptomatic thrower, the adaptive increase in external rotation results from humeral retroversion and some degree of capsular laxity, while the decrease in internal rotation is possibly the result of osseous adaptation alone.

The safe and efficient transfer of energy from the trunk to the humerus relies on the proper motion and control of the scapula. Despite the importance of the scapula, scapulothoracic motion often is an overlooked motion segment in the kinetic chain of pitching. Several recent studies have described the developmental changes in the scapulothoracic motion of the asymptomatic thrower.[15-18] Compared with control subjects, the thrower's scapula demonstrates increased upward rotation, internal rotation, and retraction during humeral elevation, as well as increased upward rotation and internal rotation in the resting position. This increased upward rotation and retraction is thought to be important during the late cocking phase of pitching because it facilitates glenohumeral articulation during extreme external rotation and horizontal abduction.[15] Conversely, a forward-tilted (protracted) scapula may exacerbate subacromial impingement or posterosuperior glenoid impingement during extreme glenohumeral external rotation.[16-18]

The complex three-dimensional nature of scapular motion makes it difficult to differentiate beneficial from detrimental motion changes. To fully understand the effect of scapular position on glenohumeral articulation, in vivo dynamic scapular motion analysis of the throwing motion is required.

Asymptomatic Pathology in the Shoulder and Elbow

The developmental and adaptive changes observed in the overhead throwing athlete can progress into asymptomatic pathology. The prevalence of asymptomatic pathology in the thrower's shoulder and elbow is significant and must be considered when making treatment decisions. Asymptomatic skeletal changes, such as proximal humeral physeal widening and medial epicondylar apophyseal separation and fragmentation, begin during participation in youth baseball.[7,9] As the skeletal structures mature, the soft tissues assume more of the joint stress associated with throwing. Magnetic resonance imaging (MRI) studies of asymptomatic elite overhead athletes document that 79% of shoulders have abnormalities in the glenoid labrum[19] while 40% demonstrate partial or full-thickness rotator cuff tears.[20] The muscles controlling the glenohumeral joint also exhibit changes that can be considered pathologic. Asymptomatic pitchers exhibit strength deficits in the dominant shoulder in the supraspinatus and shoulder external rotators compared with the nondominant shoulder.[21,22]

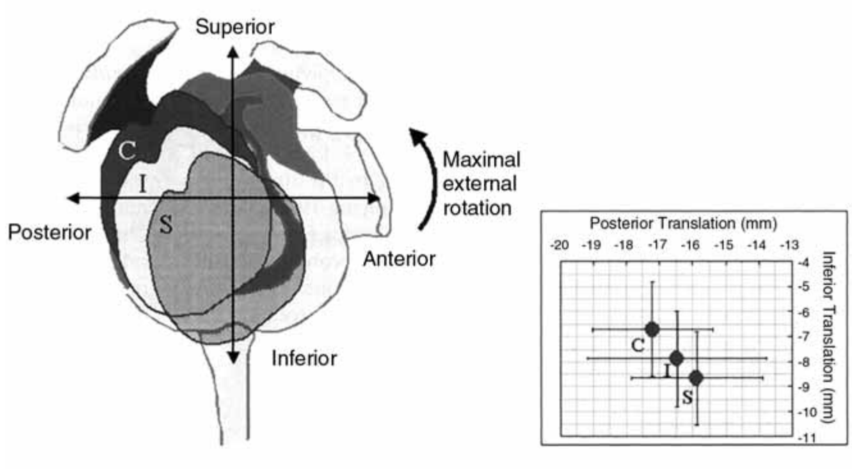
Asymptomatic pathology also is present in the elbow joint of the high-level (ie, collegiate, professional) thrower. Kooima et al[23] documented an 87% prevalence of chronic ulnar collateral ligament (UCL) injury and a correlative 81% prevalence of posteromedial osteochondral injury in the asymptomatic professional thrower. Nazarian et al[24] documented sonographic evidence and Ellenbecker et al[25] documented radiographic evidence of increased medial laxity with valgus stress in the asymptomatic major league pitcher. Treatment decisions in the injured thrower must take into account the prevalence of these largely asymptomatic findings. Asymptomatic pathology affecting the shoulder and elbow may eventually become symptomatic when the repetitive stress of throwing exceeds the ability of the body to compensate.

Mechanism of Joint Injury: Shoulder

Concepts regarding the exact mechanism of joint injury in the shoulder of the throwing athlete have evolved over many years. Our understanding of the injury process largely has been extrapolated from biomechanical evaluation of the pitching motion, intraoperative observation of anatomic injury patterns, and clinical studies reporting the outcomes of various treatments.[2,26-28] Injury is thought to occur during the late cocking phase of throwing, when the arm is in extreme external rotation and horizontal abduction. Abnormal motion of the humeral head relative to the glenoid can injure the superior and posterosuperior labrum and glenoid as well as the undersurface of the rotator cuff; this phenomenon has been called internal impingement or posterosuperior glenoid impingement. [2,18,26-28] The exact etiology and sequence of this injury pattern has not been confirmed in vivo; however, all of the following have been implicated as contributing factors in generating joint pathology: traction on the biceps tendon, laxity of the anterior band of the inferior glenohumeral ligament caused by excessive external rotation stretch, posterior capsular tightness, and scapular dyskinesis.[2,26-28]

Recent anatomic studies have quantified the effect of external rotation stretch, superior labral tears, and posterior capsular tightness on

Figure 3



Graphic simulation of humeral head position in external rotation. The humeral head moves in a posterior-inferior direction on maximal external rotation. C = simulated posterior capsular contracture, I = intact, S = stretched. (Reproduced with permission from 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;87:824-831.)

joint motion.[14,29,30] Mihata et al[14] found that pure external rotation stretch of the glenohumeral joint significantly stretched the inferior glenohumeral ligament ($P < 0.05$) and increased glenohumeral translation in the anterior, superior, and inferior directions. Panossian et al[29] reported significant increases in glenohumeral rotation ($P < 0.05$) and translation ($P < 0.05$) following superior labral tears that were corrected following surgical repair.

Grossman et al[30] quantified glenohumeral motion following external rotation capsular stretch and subsequent posterior capsular shift to simulate a posterior capsular contracture in the thrower's shoulder. When externally rotated maximally, the humeral head moved in a posterior and inferior direction in all groups (intact, external rotation stretch, external rotation stretch plus posterior capsular plication). There was a trend toward a more superior position of the humeral head in maximum external rotation following posterior capsular shift compared with the stretched state; this trend was not statistically significant[30] (Figure 3). These and future studies will help to quantify the effect of various anatomic abnormalities found in the injured shoulder of the throwing athlete.

Mechanism of Joint Injury: Elbow

The mechanism of injury in the thrower's elbow is thought to result from the valgus stress on the elbow joint created by the humeral torque generated during pitching.[2,6] Near-failure tensile stresses on the anterior band of the UCL occur during the late cocking phase of pitching.[31] This repetitive microtrauma can lead to progressive valgus instability, with attenuation of the UCL and subsequent posteromedial impingement of the elbow joint. This continuum of instability and impingement has been referred to as valgus extension overload.[32] As the UCL becomes increasingly stretched, posteromedial osseous constraint is thought to play a greater role in elbow stability during the throwing motion. Kamineni et al[33] found that the function of the anterior band of the UCL is compromised by resections of the posteromedial olecranon >3 mm. This must be taken into consideration before performing débridement procedures for posteromedial impingement because excessive resection of bone may further destabilize the elbow and expose a compromised UCL to further stress and failure.[34] The typical spectrum of disease in the thrower's elbow also includes ulnar neuritis and ulnar nerve subluxation, radiocapitellar joint injury, and even stress fracture of the olecranon.[31]

Evaluation of the Injured Thrower

Medical evaluation of overhead throwers, particularly those at the higher level, should begin before the start of and continue intermittently throughout the baseball season. Subjective complaints related to performance often precede or accompany reports of pain in the shoulder and elbow. Common complaints include loss of command of the pitch, loss of pitching velocity, a subtle change in pitching mechanics, and even symptoms distant to the shoulder and elbow joints. Early identification of these complaints requires regular communication between physicians, coaches, and athletic trainers.

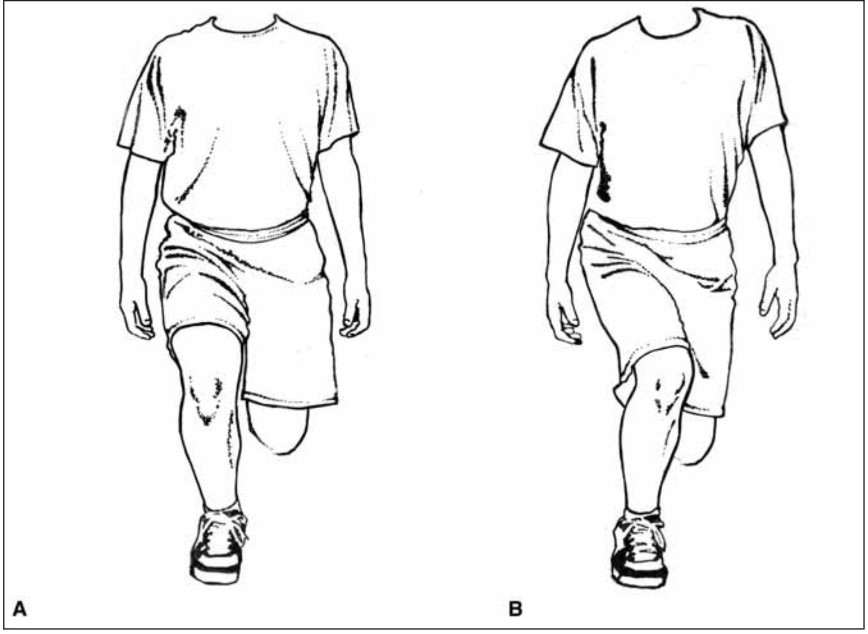
It is important that the athlete precisely define the location, onset, and duration of discomfort as well as the presence of any related neurologic or mechanical symptoms. The timing of the pain during the delivery of the pitch also can be useful in discerning the truly symptomatic pathology. For example, posterior elbow pain during terminal elbow extension may indicate valgus extension overload with posteromedial ulnohumeral impingement, whereas medial elbow pain during the late cocking phase may indicate that the

UCL is the primary pain generator. When evaluating the young pitcher, the physician also should inquire about pitch counts, rest between pitching starts, and pitch types because these factors may contribute to increased joint pain.[35]

Physical assessment of the overhead thrower requires a global evaluation. Proper conditioning of the core musculature and lower extremities is integral to the transfer of energy from the lower extremity to the upper extremity during the pitching motion.[4,17] Pathology involving the spine, trunk, and lower extremities ultimately can affect the upper extremity and should be diagnosed and corrected early. These problems include injuries to the foot and ankle, tightness of the muscles crossing the hip and knee joint, and weakness of hip abductors and trunk stabilizers, as well as conditions affecting spinal alignment and mobility (eg, degenerative joint disease).

In addition to traditional clinical assessments of the spine and lower extremity function, provocative tests, such as a dynamic Trendelenburg test, can be used to identify subtle lower extremity injuries and weakness of core musculature, both of which may affect the throwing motion and predispose the upper extremity to injury. With the patient balanced on a single leg, a partial squat is performed to dynamically test core strength and pelvic stabilization (Figure 4). Positive findings may include trunk lean to transfer weight over the stance limb and contralateral pelvic drop, as well as femoral adduction and internal rotation.

Figure 4



Dynamic Trendelenburg test. **A,** The patient performs a single-leg half squat so that the physician can evaluate core and pelvic stabilization. **B,** Positive findings include femoral adduction and internal rotation, contralateral pelvic drop, and trunk lean to balance over the stance limb.

Examination of the upper extremity begins with a careful assessment of scapular position, motion, and control. Scapular dyskinesis may indicate a primary or secondary problem in the thrower's shoulder. Primary fatigue of the periscapular muscles, caused by repetitive pitching, can contribute to abnormal glenohumeral mechanics and the development of shoulder pain. Scapular dyskinesis also can result from primary intra-articular glenohumeral pathology.[17,18] Understanding the normal scapular asymmetry found in the asymptomatic thrower will help the clinician discern pathologic from adaptive changes.[15]

Loss of the total arc of rotation, specifically with internal rotation, is a common finding in the glenohumeral joint of the injured pitcher.[18,27] This loss, which is in excess of that caused by humeral retroversion, is likely secondary to tightness of the posterior soft tissue, including the posterior rotator cuff and capsule. We agree with Wilk et al[18] that the injured thrower generally has increased posterior glenohumeral laxity on examination, which may implicate posterior rotator cuff tightness more than posterior capsule tightness as the etiology of loss of total arc of motion. Complete assessment of the shoulder also should include careful assessment of rotator cuff strength,[21,22] joint laxity,[10,11,13] and provocative tests to identify intra-articular, subacromial, and acromioclavicular pathology.

When evaluating the injured thrower's elbow, the physician must take into consideration the developmental changes and presence of asymptomatic pathology previously discussed.[7,9,19-25] In addition to increased valgus laxity, the elbow of the asymptomatic thrower commonly presents with a decreased range of motion in flexion and extension compared with the nondominant limb.[25] The spectrum of pathology in the thrower's elbow requires evaluation of the medial elbow for UCL injury, secondary injury to dynamic stabilizers (eg, the flexor-pronator group),[36] ulnar nerve injury or instability, and cutaneous nerve injury. Careful examination of the elbow may reveal posteromedial impingement, loose bodies, olecranon stress reactions, radiocapitellar osteochondral injury, tendinopathy, or symptomatic synovial plica.

Table 1

Recommended Maximum Number of Pitches*

Age (yrs)	Maximum Pitches per Game	Maximum Games per Week
8-10	50	2
11-12	65	2
13-14	75	2
15-16	90	2
17-18	105	2

* Modified pitch count guidelines from the USA Baseball Medical and Safety Advisory Committee

Reproduced with permission from Petty DH, Andrews JR, Fleisig GS, Cain EL: Ulnar collateral ligament reconstruction in high school baseball players: Clinical results and injury risk factors. *Am J Sports Med* 2004;32:1158-1164.

Table 2

Recommended Minimum Rest After Pitching*

	Number of Pitches			
Age (yrs)	1 Day of Rest	2 Days of Rest	3 Days of Rest	4 Days of Rest
8-10	20	35	45	50
11-12	25	35	55	60
13-14	30	35	55	70
15-16	30	40	60	80
17-18	30	40	60	90

* Modified pitch count guidelines from the USA Baseball Medical and Safety Advisory Committee

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Imaging studies have become a mainstay in the evaluation of the injured thrower. Plain radiography and computed tomography can be useful in the evaluation of osseous structures, while MRI is more useful for evaluating soft-tissue (eg, ligament, tendon, labrum, articular cartilage) injuries and bony edema. Depending on the quality of the MRI scan available to the physician, the use of MR arthrography may increase the diagnostic information obtained. However, the physician must take into consideration the possible discomfort following the arthrogram, which may preclude the thrower from immediate return to competition. Although these studies have added to the clinician's diagnostic armamentarium, they must be coupled with a thorough clinical assessment of the athlete and an understanding of common imaging findings in the asymptomatic thrower.[7,9,19,20,23-25]

Preventing Injuries in Throwers

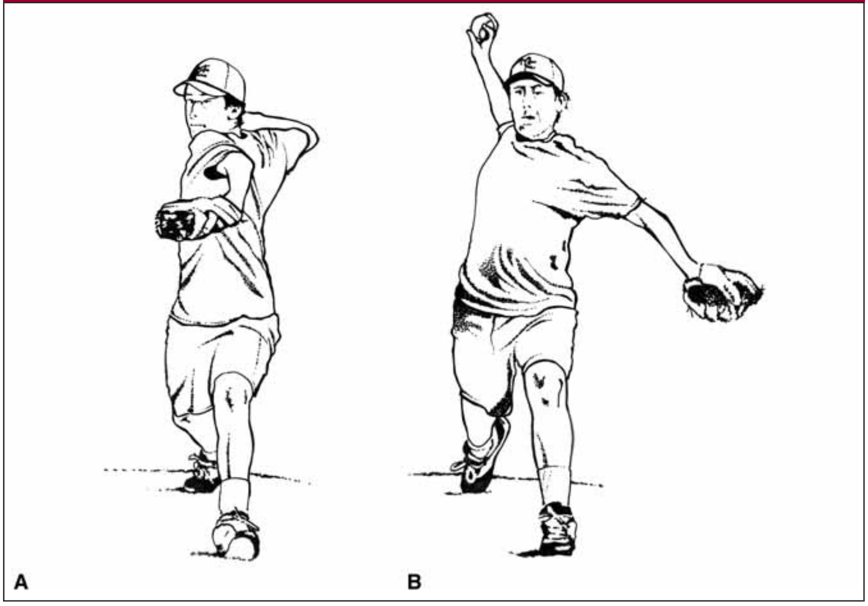
There is significant overlap between prevention and treatment in caring for overhead throwers. The repetitive microtrauma associated with throwing requires that athletes be constantly monitored for proper rest and conditioning, as well as for the development of joint symptoms. The prevalence of youth baseball in the United States necessitates that injury prevention begin as soon as athletes begin organized youth baseball. The repetitive stress of throwing most commonly injures the physis in the shoulder and elbow of the skeletally immature thrower. The physis is the weakest structural link in the kinetic chain and poorly tolerates the biomechanical stress of throwing.

The simplest way to decrease the stress of throwing is to limit the number of pitches thrown. Lyman et al[35] established the relationship between pitch count and type to shoulder and elbow pain in young pitchers. Increased pitch counts correlated with increased reports of both shoulder and elbow pain, whereas breaking balls were associated with specific joint complaints (shoulder pain was associated with curveballs and elbow pain with sliders). We recommend using the modified USA Baseball Medical and Safety Advisory Committee guidelines for specific pitch counts (Table 1) and rest between pitching starts[37] (Table 2).

Our current recommendations for preventing injury include avoiding breaking pitches (eg, sliders, curveballs) until skeletal maturity and avoiding year-round baseball. The athlete should have a minimum of 2 to 3 months of complete rest from throwing per year. It is the responsibility of the sports medicine community and its physicians not only to convey the importance of preventing injury caused by overuse but also to educate coaches and parents on the significance of shoulder and elbow complaints in the young thrower. It is a common misconception among parents and coaches that pain in the shoulder and elbow during or following baseball activities is a result of weak muscles that need to be strengthened. Joint pain related to repetitive throwing should be considered a potential injury regardless of the number of pitches thrown.

The biomechanics of pitching are often addressed at the elite level, with the goal of improving performance and possibly decreasing joint stresses. Interest has been shown recently in studying biomechanics in youth baseball in order to understand the possible relationship between pitching mechanics and joint stress. Aguinaldo et al[38] recently evaluated pitching biomechanics and humeral internal rotation torque across different levels of baseball pitchers (youth, high school, collegiate, professional) using a motion analysis system. The key parameter that differed between the various levels of pitchers was the timing of trunk rotation. Compared with less-skilled pitchers, the higher-level pitchers showed delayed trunk rotation within a given pitch cycle. The professional pitchers in the study also pitched with less humeral internal rotation torque than did the collegiate pitchers. This lends credence to the idea that early rotation of the torso ("opening up early") is inefficient and may be harmful. It is possible that initiating trunk rotation before the humerus and scapula are properly positioned can result in excessive horizontal abduction or hyperangulation (Figure 5). As our understanding of pitching biomechanics improves, we may be able to help developing throwers learn to pitch with less risk to the shoulder and elbow.

Figure 5



Delayed versus early trunk rotation. **A,** Delayed trunk rotation as the stride foot makes contact. **B,** Early trunk rotation, which is more common in pitchers with less experience.

The process of injury in both adult and youth pitchers typically occurs over time; thus, early recognition is the key to preventing permanent damage. Immediate cessation from throwing prevents further tissue injury and decreases demand on the compensatory stabilizers of the joint (periscapular and rotator cuff muscles in the shoulder, flexor-pronator muscles in the elbow). Highly competitive youth baseball and high school baseball players often are exposed to tremendous pressure to perform despite injury. Petty et al[37] reported a 74% success rate for UCL reconstruction in high school baseball players. They noted that the predominant risk factor for pitchers requiring surgery was overuse (year-round, seasonal, or event overuse) and that only 52% of these pitchers felt that their coaches were careful about preventing throwing injuries. We have observed a general trend in the patient population of younger throwers and their parents pursuing surgical treatment for preventable overuse injuries. We reserve surgery in the young athlete for conditions that have or are known to fail under nonsurgical treatment. In our opinion, the desire for a skeletally immature thrower to return to competition does not warrant the risk of physeal damage that comes with UCL reconstruction.

Preventing injury in the adult thrower begins with rest, followed by a rehabilitation program that addresses global functional deficits (eg, core stability, lower extremity strength, flexibility). Scapular stabilization, rotator cuff strengthening, and normalization of glenohumeral total arc of motion through posterior shoulder stretching is critical to throwers with symptomatic labral and rotator cuff pathology.[18] Anti-inflammatory medications can be coupled with rest and physical therapy to decrease inflammation in the injured shoulder or elbow. Improving strength and endurance of the flexor-pronator muscles, particularly the flexor carpi ulnaris, is important for secondary stabilization of the elbow to prevent and rehabilitate valgus instability.[35] Once pain and inflammation have subsided and the clinical examination has returned to baseline, an interval throwing program can be started in conjunction with continued rehabilitation.

Summary

The overhead throwing motion imparts significant biomechanical stress on the upper extremity. This repetitive joint stress alters the anatomic development of the upper extremity in young athletes. Adaptive changes and asymptomatic pathology in the shoulder and elbow progress to disabling injury when overuse exceeds the body's ability to compensate. The exact mechanism of injury is not fully understood, but it is currently thought to result from the athlete's inability to properly coordinate joint articulation during the extremes of the pitching motion. Injury prevention begins with avoiding overuse, particularly in the young thrower. To minimize stress on the shoulder and elbow joints, athletes should improve core muscle strength and scapulothoracic conditioning, maintain glenohumeral motion, and refine their pitching biomechanics.

Additional Resources

Recently published: *Advanced Reconstruction: Elbow*, edited by Ken Yamaguchi, MD, Shawn O'Driscoll, MD, Graham King, MD, and Michael McKee, MD: http://www4.aaos.org/product/productpage.cfm?code=02821

Advanced Reconstruction: Shoulder, edited by Joseph D. Zuckerman, MD: http://www4.aaos.org/product/productpage.cfm?code=02820

Related clinical topics article available on *Orthopaedic Knowledge Online*: "Elbow Valgus Instability in Throwing Athletes," by Christopher S. Ahmad, MD, and Neal S. ElAttrache, MD: http://www5.aaos.org/oko/shoulder_elbow/elbow_valgus_instab/pathophysiology/pathophysiology.cfm

CME Course: *Boomeritis: Musculoskeletal Care of the Mature Athlete*. Course Director, Richard Hawkins, MD. April 20 to 22, 2007, Hilton Head Island, SC: http://www4.aaos.org/education/mastcaldb/cmedetails.cfm?account=3106

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Evidence-based Medicine: References represent level III/IV case-control studies and level V expert opinion. References 10, 15, 16, and 25 represent comparative clinical and radiographic studies; however, there are no level I/II prospective, randomized studies on this subject.

Citation numbers printed in **bold type** indicate references published within the past 5 years.

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