

Upper Extremity Physeal Injury in Young Baseball Pitchers

Bryan M. Saltzman, MD[1]
Peter N. Chalmers, MD[1]
Randy Mascarenhas, MD, FRCSC[2]
Brian J. Cole, MD, MBA[3]
Anthony A. Romeo, MD[3]

[1]Resident, Department of Orthopedic Surgery, Rush University Medical Center, Chicago, IL; [2]Sports Medicine Fellow, Department of Orthopedic Surgery, Rush University Medical Center, Chicago, IL; [3]Professor of Orthopedic Surgery, Department of Orthopedic Surgery, Rush University Medical Center, Chicago, IL

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Abstract: Adolescent baseball players, especially pitchers, are at increased risk for shoulder and elbow injuries as their level of competition increases. The intersection of the adolescent growth spurt with the high levels of elbow valgus and shoulder rotational torques placed upon the arm during overhand pitching predisposes the shoulder and elbow to physeal injuries. *Little League shoulder* and *Little League elbow* syndromes most commonly represent pathology at the physeal regions of the proximal and distal humerus and proximal ulna sustained from repetitive loads caused by overhead throwing. There is a growing understanding that these injuries occur on a wide spectrum from delayed physeal closure and physeal widening to acute transphyseal fracture. Although operative intervention is infrequently required, patient and parent counseling can be complex. Health care professionals who care for adolescent baseball players also can play an important role in prevention. Appropriate counseling requires a comprehensive understanding of the clinical, radiographic, and biomechanical aspects of these injuries. This review summarizes these major concepts, focusing on the best available evidence from recent biomechanical and clinical studies on shoulder and elbow injuries in adolescent baseball pitchers.

Keywords: Little League shoulder; Little League elbow; physeal injury; overhead throwing; shoulder injury; elbow injury

Introduction

Adolescent baseball players, specifically pitchers, are at an increased risk for shoulder and elbow injuries as skill and level of competition increases. *Little League shoulder* and *Little League elbow* are conditions that commonly represent physeal pathology of the proximal and distal humerus and proximal ulna sustained from the repetitive valgus and rotational loads inherent to overhead throwing. The concomitant adolescent growth spurt[1] and the increasing athletic demand on these young players lead to a spectrum of upper extremity injury from delayed physeal closure or physeal widening to acute transphyseal fracture. Health care professionals who care for adolescent baseball players play an important part in patient, parent, and coach counseling to prevent what can be an avoidable condition. It is important to comprehend the various clinical, biomechanical, and radiologic facets of physeal injuries in youth baseball players, and this review summarizes the best available evidence from recent published literature on the topic.

Basic Anatomy of the Adolescent Elbow

The elbow joint has 2 degrees of freedom, flexion-extension and supination-pronation, and range of motion is generally from about 0 ° (or slight hyperextension) to about 145° of flexion. It includes 3 different articulations enveloped by a common fibrous joint

Correspondence: Bryan M. Saltzman, MD, Department of Orthopedic Surgery, Rush University Medical Center, 1611 West Harrison Street, Suite 300, Chicago, IL 60612.
Tel: 847-989-9333
Fax: 312-942-2101
E-mail: bryan.m.saltzman@gmail.com

capsule: the ulnohumeral joint, the radiocapitellar joint, and the proximal radioulnar joint. The 3 most frequently palpable osseous landmarks of the elbow are the medial epicondyle, the lateral epicondyle, and the olecranon. The trochlea runs obliquely along the distal end of the humerus, directly inferior to the olecranon fossa posteriorly and the coronoid fossa anteriorly. The trochlea forms a convex surface to articulate with the convex distal surface on the ulna, known as the trochlear notch, which allows both flexion and extension to occur at the elbow. The ulnohumeral joint, ulnar (or medial) collateral ligament (MCL) and radial (or lateral) collateral ligament (LCL) act as the respective primary stabilizers to varus stability, valgus stress, and posterolateral rotatory instability about the elbow. The LCL additionally stabilizes the elbow to varus forces.[2]

In mature overhead throwers, the ultimate load to failure of ligaments and tendons is lower than that of cortical bone, and thus these structures fail first with excessive force. However, in adolescent throwers, the mechanical weak point is the physis and thus transphyseal injuries occur before injury to the soft tissues.[2,3] These injury patterns are frequently dependent on the stage of elbow maturation. The developing elbow has 6 centers of ossification with relatively predictable rates of appearance of ossification with aging as follows: capitellum (1–2 years), radial epiphysis (2–4 years), the medial epicondylar epiphysis (5–6 years), the trochlea (8–10 years), the olecranon (about 10 years), and the lateral epicondylar epiphysis (about 12 years). However, this order of appearance is not synonymous with order of fusion. The majority of the ossification centers usually fuse between ages 14 and 16 years, with boys reaching skeletal maturity at the elbow later than girls. The medial epicondylar epiphysis is typically the last center to fuse, at about ages 15 to 16 years.[4]

Basic Anatomy of the Adolescent Shoulder

The shoulder joint is one of the most mobile joints in the human body, with the ability to flex, extend, abduct, adduct, internally and externally rotate, and move through a full 360° in the sagittal plane. The shoulder joint is composed of 4 articulations: glenohumeral, acromioclavicular, sternoclavicular, and scapulothoracic. The proximal humerus bony anatomy includes the humeral head, its anatomic and surgical necks, the greater and lesser tuberosity with intervening intertubercular grove, and the humeral shaft. The joint includes a fibrocartilaginous labrum attached around the margin of the glenoid cavity to deepen the humeral head's articulation at the glenoid fossa. The rotator cuff musculature also attaches to the proximal humerus acting as a force couple to maintain the humeral head centered within the glenoid fossa.

Similar to the elbow, the open growth plates and apophyses at the shoulder joint are susceptible to injury in a developing adolescent due to the extreme forces generated by the overhead pitching motion. There are 3 ossification centers in the proximal humerus that appear during the course of aging: the humeral head (first year of life), the greater tuberosity (2–3 years), and the lesser tuberosity (5–6 years). These physes coalesce at about age 7 years and ultimately fuse with the humeral metaphysis at around ages 16 to 20 years.[5] Because 80% of longitudinal growth of the humerus occurs at its proximal physis and because accelerated osseous growth occurs during adolescence, these growth plates are at significant risk of developing pathology.[1,6] The nearby acromion usually develops from 3 separate centers of ossification that begin to fuse in early adolescence and do not complete the process until about ages 18 to 25 years. These centers are as follows: the pre-acromial center, which provides an attachment site for the coracoacromial ligament and the deltoid's anterior tendinous origin; the meso-acromial center, which provides attachment for the middle tendinous fibers of the deltoid; and the meta-acromial center, which provides a site of origination for the posterior fibers of the deltoid.[7] Nonunion can occur at the junction between the meso-acromion and meta-acromion—termed *os acromiale*—and can be painful due to the stresses of throwing a ball.[8,9]

Basic Biomechanics of the Overhead Throwing Motion

An understanding of the basic biomechanical movements in the phases of the pitching motion is imperative to understanding how injuries about the shoulder and elbow occur.

Phases of the Pitching Motion

The pitch has been classically divided into 6 sequential phases: windup, stride, arm cocking, arm acceleration, arm deceleration, and follow-through. The windup begins with the pitcher standing on an elevated throwing mound (atop a pitching rubber) and facing home plate with the backward step of what will become the stride leg. The windup motion is initiated as the pitcher's weight shifts from the stride leg to the supporting foot and as the body rotates 90° to allow flexion and elevation of the stride leg off the ground. The windup then ends with the throwing hand leaving the gloved hand as the stride leg motions toward home plate.

The inception of the stride stage is confluent with the end of the windup and ends when the stride foot again contacts the ground in the forward direction toward home plate (ideally in line with the back foot to facilitate proper hip and trunk rotation). During this time, the throwing arm and hand are moving synchronously with the body so that the arm is in a semi-cocked position at the end of stride. Then, the arm-cocking stage has begun and the shoulder undergoes external rotation (a cocking back of the arm) as the trunk moves laterally and rotates along with the thrower's legs and hips to face home plate.

When the shoulder is maximally externally rotated, the arm acceleration stage is initiated. The humerus starts to internally rotate about the throwing shoulder, and elbow extension with concomitant shoulder internal rotation follows. The baseball is released, signaling the end of the arm acceleration phase and the beginning of arm deceleration. In this phase, the shoulder continues to internally rotate to its maximum, and the elbow continues to extend.

With the shoulder maximally internally rotated, follow-through commences. The hips continue to flex, the elbow flexes and supinates the forearm, and the stride leg extends to allow the pitcher to finish the pitching motion in a stable ready position to field a hit if necessary.[10–15] Of note, the velocity of the pitch is generated using the summation-of-speed principle, in which the driving force of the stride transfers power into the rotation of the pelvis, which then transfers power into the rotating thorax. The thorax then initiates rotation at the point of maximal pelvic angular velocity and transfers power to the humerus, which again ideally initiates rotation at the point of maximal thoracic angular velocity until this kinetic energy is transfers to the ball (Figure 1).[16,17]

In discussions of the pitching phases with coaches, parents, or even the adolescent athlete, there are commonly utilized terminologies that clinicians should be privy to. The *arm slot* refers to the angle of the throwing arm relative to the body at the point of ball release. The 3 typical arm slots used are the *12 o'clock*, the *3/4 arm slot*, and the *side arm* (or *submarine*). The *drive* is similar to the stride stage of the pitching motion in that it refers to the pitcher's push with the stable foot off of the pitching rubber as the stride foot moves toward home plate. The *rocker step* refers to the pitcher's step backward at the start of the windup stage, when the glove-side leg is at about a 45° angle from the pitching rubber. The *pivot step* is the motion when the pitcher externally rotates his arm-side leg so that the foot is then parallel with the pitching rubber. The *balance point* is the moment in the pitching motion when the glove-side leg is flexed at the hip to about 90° while the glove and throwing hand with ball are slightly above and behind the elevated thigh. Finally, the *power position* is the moment after the pitcher has progressed through the balance point to a position equivalent to the transition between the stride and arm-cocking phases of throwing.

Injury Types and Pathomechanics as a Function of Pitching Motion

The differential diagnosis of elbow pain in an adolescent thrower involves several patterns of injury that occur from chronic, repetitive microtrauma to vulnerable locations along the skeletally immature elbow. The chronic and repetitive valgus overload forces against the medial side of the elbow during the adolescent overhead throwing motion produce the characteristic Little League elbow. This entity comprises a wide variety of pathologies to the medial epicondyle, including apophysitis, avulsion fractures, fragmentation, and growth disturbance (delayed ossification or accelerated growth). Ultimately, this injury is a spectrum from physeal widening to delayed closure to physeal fracture. Although less common in the adolescent, soft tissue injury along the medial elbow may be the etiology of the patient's pain, with MCL injury, common flexor tendon pathology, and ulnar nerve neuritis included in the differential diagnosis. In a patient with pain confined more to the lateral elbow, concern should arise for skeletal injury to the capitellum, including osteochondrosis (Panner's disease), traumatic osteochondral fracture, and osteochondritis dissecans, or similar injury to the radial head.[4] The differential diagnosis for an adolescent overhead thrower with posterior elbow pain includes apophysitis/osteochondrosis, avulsion fracture or physeal

Figure 1. A pitching skeleton at rest, followed by the 6 phases of the pitching motion.

persistence, and posteromedial osteophytic impingement at the olecranon process.[4,18]

The differential diagnosis in the injured shoulder of adolescent overhead throwers includes both osseous and soft tissue injury, but, similar to the elbow, osseous abnormalities are far more common with this age group. Pathologies more likely with adult throwers including internal impingement, rotator cuff injury, and superior labral anterior-posterior (SLAP) lesions can occur in young athletes but are less likely.[19] The more likely injury pattern is the characteristic Little League shoulder growth plate injury that occurs at the proximal humerus, arising as a spectrum from physeal widening to delayed physeal closure to fracture of the physis or epiphysiolysis.

The pathomechanical motions causing Little League shoulder lie in the significant rotational stresses applied to the proximal humeral physis during the throwing motion, particularly as the shoulder changes from abduction and external rotation to adduction and internal rotation during the acceleration and deceleration phases.[5,20] Studies of adolescent physical examination have proposed that a decrease in the young athlete's shoulder elevation and total range of motion about the shoulder (particularly internal rotation with the shoulder abducted at 90°) may be consequences of bony and soft tissue adaptation to repetitive adolescent throwing motions, and could result in increased stress at the proximal humeral physis during throwing mechanics.[21]

Learning the intricacies of the 6 phases of throwing enables clinicians to then understand how the throwing motion produces injury. Little League shoulder is most likely due to the high level of torque generated during the late cocking phase and early acceleration phases. The levels of torque produced during these time periods can cause enough shear stress to result in proximal humeral epiphysiolysis.[3,10] The eccentric contraction of the subscapularis during this phase while the arm is in forced abduction and external rotation can acutely—or with chronic overuse—avulse the lesser tuberosity from the humerus[22] or sustain fragmentation to the superior glenoid rim.[23] The highest internal rotation velocity at the shoulder is during the arm acceleration phase, and this velocity poses a threat to the proximal humerus. The highest stress on the shoulder is in fact a large distraction (or compressive) force at the time of ball release; this may be the most damaging force on the shoulder as it is severalfold greater than the anterior force on the joint at acceleration.[3,24,25]

The elbow is at risk of physeal injury in part during the late arm cocking phase as valgus torques across the elbow begin to peak during this period. These forces increase exponentially during the arm acceleration phase and result in loads that approach the ultimate failure strength of the MCL and can accordingly lead to medial physeal pathology.[2] The same valgus force that causes a distractive force medially leads to a compressive force laterally and can lead to osteochondritis dissecans of the capitellum.[2] The olecranon is loaded during active extension of the elbow, and impingement on the olecranon fossa occurs during cocking and follow-through, with the potential therein for injury.[2,14] The medial cortical notch of the proximal ulnar trochlear groove is a stress riser that may contribute to stress fractures at this location due to the repetitive elbow valgus and hyperextension seen between late cocking and ball release.[26]

Common Injuries Sustained in Adolescent Overhead Throwing Athletes

Little League elbow and *Little League shoulder* occur as a result of age-related anatomical characteristics. Brogdon and Crow[27] first described Little Leaguer's elbow in 1960 as soft tissue swelling and pain over the medial epicondyle of the throwing elbow, with radiographic evidence of avulsion and fragmentation of the affected medial epicondyle epiphysis in adolescent baseball players. These authors hypothesized that tension on the common flexor-pronator mass resulting from extremely vigorous contraction caused this phenomenon. This condition is part of a spectrum of elbow injuries in young pitchers that also includes posteromedial elbow impingement and capitellar osteochondritis dissecans.[28] Additional pathologies of the adolescent thrower's elbow include stress lesions of the proximal ulna limited to the trochlear groove,[26] fractures of the sublime tubercle,[29] and nonunion or stress fractures of the olecranon through the physeal plate or abnormal persistence of this physis into skeletal maturity.[30,31]

In 1953, W.E. Dotter[32] first described Little Leaguer's shoulder as osteochondrosis of the proximal humeral epiphysis, with radiographic signs of a fracture line through the epiphyseal cartilage of the proximal humerus in association with shoulder pain during the act of overhead throwing in the skeletally immature athlete. Authors over time have described this association in concert with demineralization, epiphysiolysis, and physeal widening of the proximal humerus resulting from repetitive microtrauma due to the large rotational torques sustained during the throwing motion.[33] Little League shoulder typically occurs in male baseball pitchers aged between 11 and 14 years, due to the proximal humeral physis being at its peak growth phase during this time.[34,35] Additional pathologies of the shoulder include lesser tuberosity avulsions, which can occur as a fracture through the tuberosity's apophyseal plate remnant,[22,36] painful os acromiale from failure of bony union of the ossification centers of the acromion,[8] and superior glenoid stress lesions including superior Bennett lesions.[37,38]

Little League Shoulder and Elbow: Clinical Workup

Risk Factors for Injury

Numerous specific risk factors have been discussed for the development of Little League shoulder and Little League elbow in adolescent overhead throwers (Tables 1 and 2).[39,40] Some studies have proposed that breaking pitches (curveballs and sliders) increase the risk of elbow and shoulder pain and injury,[41] although others dispute this claim.[11,42] The association between injury and increased number of pitches thrown per game, innings per season, and months pitched per year has been demonstrated in multiple studies.[40,41] Olsen et al[43] reported that the strongest associations with shoulder and elbow injuries in their cohort of adolescent baseball pitchers were overuse and fatigue pitching, with additionally high correlations from high pitch velocity and participation in pitching showcases. Of note, some of the aforementioned risk factors, including the use of breaking pitches at an early age and high-velocity pitching, may be related to soft tissue pathology at these joints as well, most notably the MCL.[44]

Eliciting a History From the Adolescent Overhead Throwing Patient

General sports-related questions for the patient and the patient's parents or coaches should address the athlete's position (particularly if he pitches), the number and type of pitches thrown per game and per season, the frequency of pitching, and the number of leagues in which the patient plays. A detailed pain history should be ascertained, including the quality, severity, and specific location of pain experienced; the temporality of the pain (acute vs chronic); when the pain occurs (for example, in which part of the pitching motion); and previous treatments received for the pain and whether they were helpful or not.[4,20,35] The patient's chronological age and skeletal age should each be noted.

Table 1. Risk Factors for the Development of Elbow Pain[39,40]

Increased age
Increased weight
Decreased height
Lifting weights during the season
Playing baseball outside of a single competitive league
Decreased self-satisfaction with pitching performance
Arm fatigue during the game pitched
Throwing $<$ 300 pitches during a single baseball season
Throwing $>$ 600 pitches during a single baseball season
Pitching for concurrent teams
Pitchers who also play catcher
Poor pitching biomechanics (causing increased torque and force at the elbow)

Table 2. Risk Factors for the Development of Shoulder Pain[39]

Decreased self-satisfaction with pitching performance
Arm fatigue during the game pitched
Throwing $>$ 75 pitches in a game
Throwing $<$ 300 pitches during the season

Physical Examination of the Adolescent Elbow

On physical examination of the elbow, simple inspection enables the clinician to note atrophy or hypertrophy about the joint, as well as abnormalities in gross overall alignment. Local tenderness or soft tissue swelling should be noted with its location in relation to bony landmarks about the elbow. Direct palpation should include certain key sites to evaluate pathology: the soft spot of the elbow for synovitis, the posteromedial and posterolateral ulnotrochlear joint line for osteophytes and synovitis, along the course of the ulnar nerve for the reproduction of neurologic symptoms distally, and the common flexor-pronator mass for pain and increased tension. Palpation should also be performed at the medial epicondyle, the MCL, the sublime tubercle of the ulna, the olecranon physis, along the medial column of the physis itself, and laterally along the radiocapitellar joint line for point tenderness. The patient should be examined for pain on active and passive flexion/extension and pronation/supination of the forearm. Range-of-motion and strength-with-motion testing should be documented. Stability testing is also important, especially with the milking maneuver and moving valgus stress tests (Figure 2).[4,27,28] The milking maneuver requires the clinician to create a valgus stress on the patient's elbow with the forearm supinated and the elbow flexed $>$ 90°. With the moving valgus stress test, the valgus stress is applied to the elbow as it is moved through its flexion-extension arc. The contralateral elbow should be examined for comparison.

Physical Examination of the Adolescent Shoulder

Physical examination of the shoulder joint should similarly include inspection, palpation, and range-of-motion testing. The

Figure 2. Physical examination of the elbow demonstrating the milking maneuver and the moving valgus stress test.

shoulder and thorax should be observed from both the patient's front and back. The physician should also specifically look for tenderness with palpation over the proximal humerus laterally or anteriorly; loss of muscle strength about the shoulder (particularly in external rotation); pain with resisted movements (including external rotation, internal rotation, thumb-down forward flexion, flexion and abduction in the plane of the scapula with the arm abducted 90°); and measurement of internal and external rotation in abduction with the patient supine and the scapula stabilized to search for glenohumeral internal rotation deficits.[20] Belly press or lift-off testing on physical examination are imperative to assess the integrity of the subscapularis and its insertion at the lesser tuberosity.[36]

Pain over the acromion and positive impingement signs with provocative maneuvers that load the acromioclavicular joint (including the cross-body adduction test and the O'Brien's active compression test) can be indicative of a painful unfused acromial apophysis.[8] Patients with lesions about the glenoid and glenoid rim may have pain provoked with palpation over the posterior glenohumeral joint space, testing specific for SLAP lesions (ie, O'Brien's test), and with forced external rotation at 90° of abduction palpating over the posterior glenohumeral joint, or pain with the arm in abduction and external rotation.[37] Although there currently is no single test for reliably making the diagnosis of a SLAP lesion, it is recommended that the examiner consider performing an active compression test (O'Brien's test), a dynamic shear test, and a Kim test. In all cases, the contralateral shoulder should also be examined for comparison.

Radiographic Assessment of the Elbow

It is important to obtain a full set of plain radiographic images at the inception of the patient workup (Table 3). As with physical examination, obtaining contralateral elbow films is important to assist in the differentiation between what is truly pathologic and what is normal or a slight variation thereof. Stress fluoroscopy of the elbow may aid in the evaluation of any dynamic instability of the joint.[3] Elbow radiographs should be used to assess the medial epicondylar physis, the capitellum, the radial head, and the olecranon physis. The relevant physes should be evaluated for hypertrophy (accelerated growth), sclerosis, widening with or without fragmentation of the ossification center, and any observed differences in comparison to the contralateral films.[4,20,45]

Advanced imaging can be performed if the radiographs are inconclusive or further characterization of pathology is required. In these cases, magnetic resonance imaging (MRI)

Table 3. Plain Radiograph Views in the Workup of Little League Upper Extremity Injury

Elbow joint
AP
Lateral
Oblique
Shoulder joint
AP Grashey
Scapular-Y lateral
Axillary lateral
Internal rotation
External rotation

Abbreviation: AP, anteroposterior.

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can be helpful. T1-weighted sequences may show extension of physeal signal intensity into the metaphysis as a sign of physeal widening.[46] Magnetic resonance imaging can also be used to evaluate ligamentous pathology such as a tear in the MCL of the elbow or avulsion from the sublime tubercle,[47] chondral pathology including osteochondritis dissecans, or osseous pathology such as edema and nondisplaced fractures that may not be evident on plain films.[4,28] It can additionally confirm stress fractures that go otherwise undetected on plain radiographs.[26] It has been suggested that MRI can be a helpful technique for serial examination of treatment efficacy.[48] Magnetic resonance arthrography may be helpful in determining if there is a tear of the inner fibers of the MCL and can be of use in determining the stage of osteochondral lesions. Computed tomography is proposed to be of use in patients with posterior elbow pain and negative radiographs in order to search for fracture lines involving the olecranon physis.[49]

Radiographic Assessment of the Shoulder

Table 3 similarly describes the relevant plain radiographic images necessary in evaluating the shoulder joint. Contralateral films should additionally be obtained to look for pathologic changes versus normal anatomic variants. The proximal humeral physis should be the focus of the radiographic imaging of the shoulder. As with the discussion of the elbow radiographs, the relevant physes should be evaluated for hypertrophy (accelerated growth), sclerosis, widening with or without fragmentation of the ossification center, and any observed differences in comparison with the contralateral films.[4,20,45] As noted by Carson and Gasser,[20] the classic widening of the proximal humeral physis in Little League shoulder can be seen most easily on anteroposterior (AP) internal and external rotation radiographs of the proximal humerus (Figures 3 and 4). Figure 3 depicts a partial avulsion fracture with mild displacement of the medial epicondyle, an example along the spectrum of Little League elbow. Only the distal third is displaced in this example. Figure 4 offers evidence of widening of the proximal humeral physis (termed epiphysiolysis). The AP radiographic views often demonstrate the avulsed bony fragment below the glenoid in lesser tuberosity avulsions, but the axillary view can better show more subtle fracture lines.[50] The AP and axillary views provide sufficient definition of os acromiale when present as well.[9] The addition of 45° craniocaudal plain radiograph views may be helpful in finding lesions of the superior glenoid rim.[37] An MRI may have additional value as described above for soft tissue injury or serial treatment evaluation. It can detect some stress

Figure 3. A) Anteroposterior and **B**) oblique radiographs of Little League elbow. **C**) Anteroposterior and **D**) oblique views of an uninjured elbow with normal open physes for comparison.

lesions earlier than routine radiographs. Magnetic resonance arthrography is often the test of choice for evaluating patients who are suspected of having SLAP lesions.

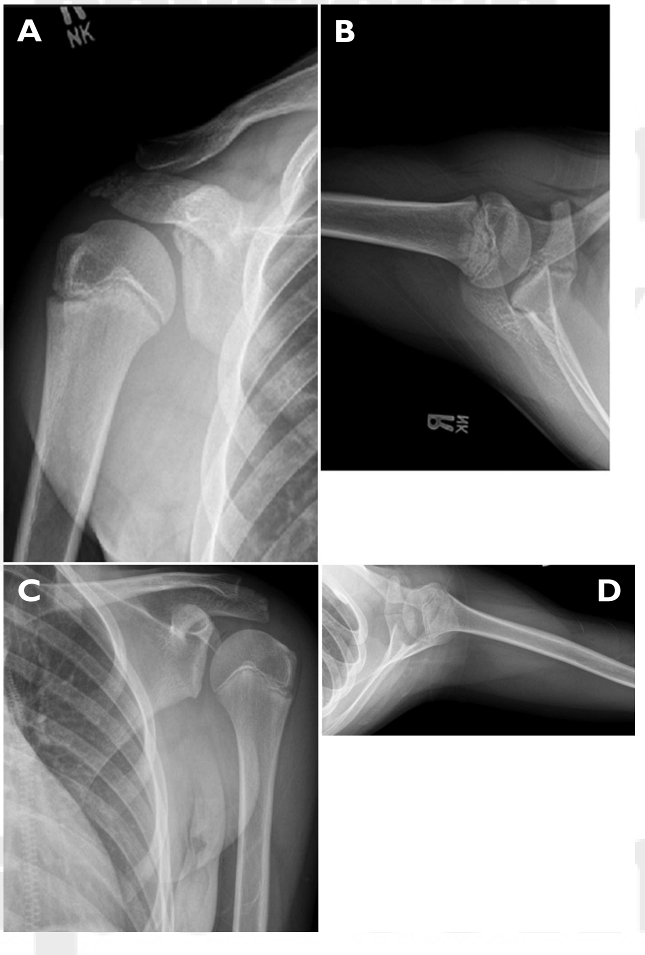
Clinical Studies on Little League Elbow Injury

Many clinical studies over the past several decades have characterized the various aspects of Little League elbow. Larson et al[51] evaluated 120 Little League pitchers aged 11 and 12 years, with mean pitching experience of 2.75 years. They found that 25 of 120 pitchers (21%) had symptoms or tenderness about the dominant elbow, and 35 of 120 pitchers (29%) exhibited radiographic changes such as enlargement, fragmentation, separation, or irregularity of the medial epicondyle. Grana and Rashkin[52] evaluated 73 baseball pitchers (average age, 17 years) and found that 58% reported pain while throwing and 56% had radiographic changes. Hang et al[53] studied 343 Little League players of various positions and found that all pitchers and catchers and 90% of fielders demonstrated radiographic evidence of medial humeral epicondyle hypertrophy, and that catchers, but not pitchers, had the greatest rate of medial epicondyle separation and fragmentation (although these changes were present in players at every position).

Wei et al[28] evaluated plain radiographic and advanced imaging findings on MRI in 9 adolescents with known Little League elbow. They reported radiographic findings such as frank fragmentation of the medial epicondyle apophysis, hypertrophy of the medial epicondylar apophysis, thickness of the medial humeral cortex, and separation from the humeral metaphysis of the medial epicondyle apophysis. The MRI findings were more prevalent and included tendinopathy of the common flexor mass, humeral metaphyseal edema, and epiphyseal edema. In one acute variant, Osbahr et al[54] described the radiographic findings of Little League elbow in 8 adolescent baseball players who had experienced an episode of sudden pain, swelling, and tenderness of the medial epicondyle with a throwing motion. They characterized these acute medial epicondyle fractures with displacement averaging 5.1 mm as being in contrast to the more insidious changes seen in typical Little League elbow. The authors found the patients with ≤ 5 mm of displacement did well with nonoperative treatment, and those with > 5 mm of displacement required and did well with open reduction and internal fixation (ORIF) of the displaced fragment (Figure 5).

Figure 5. A) Anteroposterior and **B**) lateral radiographs demonstrating operative treatment for Little League elbow, a medial epicondyle fracture treated with open reduction and internal fixation with a screw construct.

Figure 4. A) Anteroposterior and **B**) axillary lateral radiographs of Little League shoulder. **C**) Anteroposterior and **D**) axillary views of an uninjured shoulder with normal open physes for comparison.



Shukla and Cohen[55] studied 5 male athletes (involved in such athletic activities as baseball, martial arts, and hockey at their respective times of injury) with symptomatic medial epicondyle nonunions after a course of nonoperative treatment from time of athletic injury. They reported 100% patient satisfaction and bony healing with significantly improved postoperative extension, low Disabilities of Arm, Shoulder, and Hand (DASH) scores (mean, 0.8), high Mayo Elbow Performance scores (mean, 100), and 100% return to high levels of physical activity after treatment with ORIF using a tension band construct.

In the single reported adolescent baseball pitcher with a stress fracture of the trochlear groove of the proximal ulna, nonoperative treatment with rest, physical therapy, and a bone stimulator for 5 months resulted in the patient's return to play.[26] Salvo et al[29] described 8 male adolescent baseball players (mean age, 16.9 years) who had sustained an avulsion fracture of the sublime tubercle of the ulna. All 8 had medial elbow pain with overhead throwing that began after a single throwing episode; 7 patients (88%) had pain on valgus stress testing and 1 (12%) had laxity on examination. Nonoperative treatment failed in 6 patients (75%), and these players

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underwent successful primary repair or reconstruction with successful results in all.

Stress fractures through the olecranon epiphyseal plate have been reported sparsely in the literature as well. Torg and Moyer[56] reported the first case in a 16-year-old baseball pitcher who was treated successfully by excision of the nonunion and grafting of autogenous bone. In a case series by Rettig et al[31] of 5 adolescent baseball pitchers (mean age, 15 years) with a mean loss of 5° of elbow extension and 4° of elbow flexion who were found on radiographic evaluation to have this injury type, the authors demonstrated that treatment with ORIF via cancellous screw and washer with or without tension banding was successful in providing excellent clinical results with minimal complications. A small case series of 6 adolescent throwing athletes (5 baseball pitchers and 1 softball pitcher) by Fujioka et al[49] additionally demonstrated the utility of surgical treatment with internal fixation by cannulated screw to enable early return to competitive adolescent sports activity.

Clinical Studies on Little League Shoulder Injury

Numerous studies have been conducted to determine the incidence of these Little League shoulder injury and to describe its various presentations. Meister et al[21] reported on changes in Little League baseball players' glenohumeral rotational motion aged between 8 and 16 years in a cross-sectional study of 294 baseball players, and found significant variance of motion between age groups, including elevation (174.1° for 16-year-olds vs 179.6° for 8-year-olds) and internal rotation (21.3° for 16-year-olds vs 39.0° for 8-year-olds) in the dominant arm. The most dramatic total range-of-motion decline was seen between 13- and 14-year-old throwers, indicating the change in motion that takes place with increasing skeletal maturity.

Mair et al[33] studied 79 male adolescent baseball players and found that in a similar percentage of players who either had a history of shoulder symptoms during the current season (26 patients) or who never had shoulder pain (53 patients), the proximal humeral physis was widened appreciably on radiographic imaging (62% vs 55%). On physical examination, the older players had an increased amount of external rotation in the dominant shoulder compared with that in the contralateral shoulder. The study demonstrates that the radiographic changes in Little League shoulder can be evident in an asymptomatic thrower as well.

Lesser tuberosity avulsion fractures in skeletally immature patients have been reported in adolescent baseball players relatively infrequently in the literature. Garrigues et al[36] reviewed a cohort of 6 patients with the injury type treated with an open reattachment of the tuberosity using suture anchors; 1 patient's injury was due to baseball. He was a 14-year-old with a dislocation injury to the shoulder and a concomitant humeral avulsion of the glenohumeral ligaments who at 6.5 years follow-up was doing well and playing Division I baseball. Sugalski et al[22] presented a case report of a 15-year-old baseball pitcher who had injured his dominant shoulder 10 weeks prior to presentation and had sustained an avulsion fracture of the lesser tuberosity. He had participated in multiple leagues with competitive throwing 10 months out of the year, pitching 1 to 2 games each week and averaging 5 to 6 innings each game, and 60% of his pitches were fastballs.

Painful os acromiale in adolescent baseball players has been described sparingly in the literature, with 1 report of a baseball catcher who presented after an acute traumatic event.[9]

With traditional Little League shoulder, excellent outcomes have been described with nonoperative treatment, with a minority of patients requiring operative intervention. Carson and Gasser[20] treated 23 young baseball players with radiographic Little League shoulder nonoperatively, with a mean of 3 months' rest from overhead throwing activity. Athletes were able to return to play at a rate of 91% (21 of 23; the other 2 athletes were still resting at the time of manuscript submission), indicating successful outcomes with nonoperative treatment of Little League shoulder.

Torg et al[57] suggested that clinical improvement of symptoms may be more valuable in determining when throwing can resume, given that return to normal radiographic appearance of the physis can take months to occur due to the remodeling process. The return to throwing should be low-intensity, low-speed short toss, as there is evidence from Fleisig et al[58] to suggest that a long toss introduces just as much torque through the upper extremity as does a full pitch. With lesser tuberosity avulsions, nonoperative management risks malunion with subcoracoid impingement and loss of rotation, nonunion, instability, and continued pain.[36]

Vezeridis et al[59] reported on 8 patients with sports-related lesser tuberosity avulsion—only 1 of which sustained the injury from baseball—with a mean age of 13.3 years who underwent ORIF. All 8 achieved pain relief, full return of internal rotation strength, high satisfaction, and excellent shoulder function, and all returned to their respective sport at a mean 4.4 months postoperative. In the previously referenced case report by Sugalski et al,[22] the patient's displacement was minimal and he was successfully treated nonoperatively.

Surgical fixation of painful os acromiale has not been evaluated in the specific population of adolescent throwers, although ORIF has been described in adult populations.[60] Similarly, treatment of superior glenoid rim lesions has not been evaluated in the specific population of adolescent throwers, but in a report of 5 athletes with superior Bennett lesions—3 of them adult male baseball players—with a mean age of 30 years, arthroscopic resection of an unstable mobile bony fragment at the posterosuperior medial glenoid rim resulted in return to play by 2 years postoperative in all athletes.[37]

Comparison of Adult and Adolescent Throwers

A few other studies on adult or professional baseball pitchers have concluded that significant associations exist between maximum pitch velocity and elbow injury,[61] and that the late cocking phase has a critical point of high torque levels at the shoulder and elbow, and can result in increased risk of injury.[13] Authors have also found that valgus torque at the elbow during pitching is closely related to late trunk rotation, reduced shoulder external rotation, and increased elbow flexion.[16] These concepts are not unlike what has been described above in the adolescent pitcher. Ramappa et al[62] studied 39 professional and 13 young pitchers with high-speed videography and determined that young pitchers experience significant anterior shoulder forces and internal rotation torques, although at much lower magnitudes than those seen in their professional adult counterparts. Although young pitching mechanics differ from adult mechanics, these studies highlight that an early focus on good technique is necessary to provide young pitchers with injury-free play into adulthood.

Prevention Strategies

These clinical and biomechanical studies on shoulder and elbow pathology in adolescent pitchers provide clinicians with a potential roadmap to injury prevention. A common theme from these reports is the importance of promoting proper pitching mechanics along the entirety of the body (arms, torso, and legs).[10,12,63] Pitch count, inning count, and the number of batters faced are important approaches to injury prevention (Table 4). A young pitcher should be taken out of a game if he develops arm fatigue or pain, decreased accuracy or ball speed, or increased time between pitches.[39,40] Pitchers should avoid playing in games outside of their primary competitive league, and they should take several months off from overhead throwing each year to avoid overuse and difficulty in maintaining pitch counts.[40] It may be prudent to include clinical shoulder and elbow range of motion and strength examination in preathletic participation screening, given that there is a relationship between shoulder strength and motion and pitching biomechanics.[64] Physicians should be included early on in the Little Leaguer's career to recognize signs and symptoms of impending injury prior to significant damage occurring.

Table 4. Suggested Limitations by Pitch Count, Inning Count, and Batters Faced for Young Overhead Throwers[39–41]

Timing Designation	Suggested Limitation
Pitches per game	75
Pitches per season	600
Innings per year	100
Batters faced per game	15
Batters faced per season	120

Table 5. USA Baseball Medical and Safety Advisory Committee Pitch Count Limits[65]

9–10 Years Old	11–12 Years Old	13–14 Years Old
50 pitches/game	75 pitches/game	75 pitches/game
75 pitches/week	100 pitches/week	125 pitches/week
1000 pitches/season	1000 pitches/season	1000 pitches/season
2000 pitches/year	3000 pitches/year	3000 pitches/year

Table 5 depicts the most current recommendations on daily, weekly, per season, and per year pitch count limit recommendations from the USA Baseball Medical and Safety Advisory Committee.[65] In their epidemiologic study of 476 young (ages 9–14 years) baseball pitchers over the course of a single season, Lyman et al[41] found a significant association between the number of pitches thrown in a game and during a season and the rate of elbow pain and shoulder pain, which helps provide evidence for these recommendations.

Conclusion

Because of anatomic and biomechanical differences, the injuries produced in skeletally immature pitchers are analogous to, but very different from, those seen in skeletally mature pitchers. Although young pitchers generate lower shoulder and elbow torques than do adults,[10,62] medial elbow pain and radiographic changes at the medial epicondylar physis and proximal humeral physis are common in this patient population. Fortunately, the majority of these injuries respond to nonoperative treatment and a throwing holiday of several months, followed by a gradual return to throwing when the affected joint is asymptomatic; this is the first-line treatment.[20] Stretching (ie, sleeper stretch, side-lying cross-body stretch) as well as strengthening exercises (rotator cuff, periscapular musculature, and flexor-pronator mass) are also worthwhile for rehabilitation and prevention of reinjury.[19] In acute displaced fractures of the medial epicondyle, ORIF can be considered.[4,54,66] Athletes, parents, and coaches should be informed about the risk factors for injury, particularly fatigue. Pitch counts must be recorded and limits enforced to prevent injury, especially for players playing on multiple teams who may not have a single coach who is aware of all of their play.

Conflict of Interest Statement

Bryan M. Saltzman, MD, Peter N. Chalmers, MD, and Randy Mascarenhas, MD, FRCSC, have no conflicts of interest to declare. Brian J. Cole, MD, MBA, is a consultant to Arthrex. Inc., DJ Orthopaedics, Johnson & Johnson, Regentis, and Zimmer; a member of the advisory board of Elsevier, AAOS, the *American Journal of Orthopedics, Cartilage,* the Arthroscopy Association of North America, the *Journal of Bone and Joint Surgery-American,* and the *Journal of Shoulder and Elbow Surgery;* a stockholder in Carticept and Regentis; and has received research funding from Johnson & Johnson, Medicpost, and Zimmer. Anthony A. Romeo, MD, is a consultant and speaker for Arthrex. Inc.; a member of the spaker's bureau of Arthrex, Inc., a member of the advisory board of the *Journal of Shoulder and Elbow Surgery,* SLACK Incorporated, *Orthopedics Today, Sports Health, Techniques in Shoulder and Elbow Surgery, Operative Techniques in Sports Medicine,* the *Orthopaedic Journal of Sports Medicine,* the American Orthopaedic Society for Sports Medicine, American Shoulder and Elbow Surgeons, and the Arthroscopy Association of North America; and has received research funding from Arthrex, Inc., DJO Surgical, Smith and Nephew, and Ossur.

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