Shoulder and Elbow Injuries in the Skeletally Immature Athlete

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Abstract

The intensity of training and competition among young athletes can place them at increased risk of acute and chronic injuries, which occur in patterns unique to the skeletally immature athlete. Prompt recognition and treatment of these injuries are critical to prevent long-term functional disability and deformity. Children and adolescents participating in recreational and organized sports are particularly susceptible to a broad spectrum of shoulder and elbow injuries involving both osseous and soft-tissue structures. Understanding the relevant functional anatomy, biomechanics of throwing, and pathophysiology of injury can help the clinician manage common acute traumatic injuries, some of which may result in chronic problems. Overuse injuries occur more frequently than do acute, traumatic injuries, and early recognition, coupled with appropriate treatment or prevention, can help restore and maintain normal shoulder and elbow function.


Shoulder and elbow injuries in the skeletally immature are becoming more frequent as more children and adolescents participate in recreational and competitive athletics requiring repetitive overhead motion. Although most of these injuries result from chronic overuse, traumatic injuries to the shoulder and elbow also occur. The injury patterns in these patients are distinct because their developing physes are relatively weak. Whereas injuries in adults tend to involve ligamentous and soft-tissue structures, injuries in the skeletally immature commonly involve the physis as well.

Shoulder and Elbow Anatomy

To manage these injuries effectively, clinicians should understand functional shoulder and elbow anatomy in children and adolescents, as well as the normal developmental sequence of the primary and secondary ossification centers, which represent potential sites of injury.

Shoulder

The proximal humeral physes, which has formidable growth and remodeling potential, contributes approximately 80% of the longitudinal growth of the upper extremity. It is composed of three primary ossification centers—the humeral head, the greater tuberosity, and the lesser tuberosity—that coalesce between the ages of 5 and 7 years to form a single proximal humeral epiphysis. Subsequently, the proximal humeral physis fuses approximately between the ages of 14 and 17 years in females and 16 and 18 years in males.

The capsuloligamentous and muscular structures of the shoulder provide static and dynamic stability of the glenohumeral joint. The static stabilizers function primarily at the extremes of the range of motion (ROM) as they reciprocally tighten and loosen to limit humeral head translation. The dynamic stabilizers provide stability during the midrange of motion, when the static stabilizers are lax. The dynamic stabilizers contract in a coordinated pattern to provide concavity-compression of the humeral head within the glenoid cavity, limiting abnormal translation.

Different portions of the joint capsule, glenohumeral ligaments, and glenoid labrum provide static glenohumeral stability, depending on the position of the arm. The anterosuperior capsule, coupled with the structures of the rotator interval, limit inferior and posterior translation of the...
humeral head in the adducted arm. The middle glenohumeral ligament functions to limit anteroposterior (AP) translation in the abducted arm at the midrange of external rotation. The inferior glenohumeral ligament, a complex structure possessing anterior and posterior bands with an interposing axillary pouch, serves as the primary restraint to AP as well as to inferior translation in the abducted and maximally externally rotated arm. The posterior capsule, which does not have any direct posterior ligamentous reinforcements, is important in limiting posterior humeral translation in the adducted, internally rotated, and forward-flexed arm. Overall static stability is further enhanced by the labrum, which deepens the concavity of the glenoid socket in both the AP and superior-inferior dimensions. The labrum also acts as an anchor point for the capsuloligamentous structures and the long head of the biceps tendon. Labral injury or detachment is a potential site of injury. The posterior band, because of its primary stabilizing role at higher degrees of elbow flexion, is functionally more important than the anterior band in the overhead throwing athlete.

Originating from the medial epicondyle, the flexor-pronator musculature provides dynamic valgus stability of the elbow. From proximal to distal, this muscle mass includes the pronator teres, flexor digitorum profundus, palmaris longus, flexor digitorum superficialis, and flexor carpi ulnaris. Electromyographic (EMG) and biomechanical studies have shown the pronator teres, flexor digitorum superficialis, and flexor carpi ulnaris muscles, which form musculotendinous units overlying the UCL complex, to be primarily responsible for maintaining dynamic valgus stability.

The lateral collateral ligament complex is less well understood than the medial ligamentous structures. It is composed of three distinct portions: the radial collateral ligament, the lateral UCL, and the accessory lateral collateral ligament. The lateral UCL has been shown to be the primary restraint against rotatory subluxation of the ulnohumeral joint; injury to this structure allows posterolateral rotatory instability to develop. The radial collateral ligament is reportedly an important secondary restraint of the lateral elbow, along with the extensor muscles, including the extensor digitorum communis, brachioradialis, and extensor carpi radialis longus and brevis. These muscles impart dynamic stability to the lateral elbow. EMG studies have shown that they exhibit complex, interdependent firing patterns throughout the throwing motion; thus, they may be vulnerable to overuse injuries.

**Biomechanics of Throwing**

The overall motion and kinematics of throwing in adolescents are similar to...
those in adults, with stresses that are similar but of lesser absolute magnitude.16 Proper throwing mechanics can and should be taught at a young age, along with strengthening of the upper extremity, to reduce injury rates.

Although specific techniques of overhead throwing vary with different sports, the basic motion is similar. The baseball pitch has been the most studied and can be divided into five main stages8,17 (Fig. 1). In stage 1, or windup, the elbow is flexed and the shoulder is in slight internal rotation; muscular activity is minimal. Stage 2, or early cocking, begins when the ball leaves the nondominant gloved hand and ends when the forward foot contacts the ground. The shoulder begins to abduct and rotate externally. This stage entails early activation of the deltoid followed by activation of the supraspinatus, infraspinatus, and teres minor muscles.5,6,8,17

Stage 3, or late cocking, is characterized by further shoulder abduction and maximal external rotation as well as increasing elbow flexion and forearm pronation. Activity levels of the supraspinatus, infraspinatus, and teres minor reach their peak during the midportion of this phase, and subscapularis and periscapular muscular activity increase.6,8,17 Tremendous shear forces are generated across the anterior shoulder, predominantly by the rotator cuff muscles.16,17 The long head of the biceps and the subscapularis also contribute to dynamic anterior shoulder stability during late cocking.5,9

In stage 4, or acceleration, the shoulder musculature generates a large forward force on the extremity, resulting in internal rotation and adduction of the humerus coupled with rapid elbow extension.5,6,17,18 Working in concert with the periscapular muscles, the subscapularis exhibits high activity during this stage.5,6,17,18 Stage 4 ends with ball release as tremendous valgus stresses are generated about the medial elbow structures.13,18 The anterior bundle of the UCL bears most of these forces. Secondary supporting structures, such as the flexor-pronator musculature, facilitate transmission of these significant stresses. Most elbow injuries occur during this stage because these forces are concentrated on the medial elbow structures. Ball release also generates tremendous compression and rotatory stresses laterally in the radiocapitellar articulation, and powerful triceps contraction imparts tensile forces in the posterior compartment.13,19

In stage 5, or follow-through, all excess kinetic energy is dissipated as the upper extremity decelerates rapidly. The stage ends when all motion is complete. Forceful deceleration of the upper extremity occurs as the elbow reaches full extension and the shoulder is maximally internally rotated.8,13 The biceps and brachialis exhibit high activity levels during this phase, as does the posterior cuff musculature, which contracts eccentrically to stabilize the glenohumeral joint.5,9 The deltoid, latissimus dorsi, and subscapularis muscles contribute to shoulder stability and prevent humeral head subluxation. Tremendous torque is generated across the glenohumeral joint as the arm rapidly decelerates.5,18

Figure 1 Phases of the throwing motion in baseball. (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.)

Acute Injuries of the Shoulder and Elbow

Traumatic osseous and soft-tissue injuries of the shoulder and elbow in the skeletally immature athlete span a wide range of injury patterns, some of which may lead to chronic instability. The most commonly observed acute injury patterns in this population are glenohumeral dislocations and acute medial epicondylar fractures.

Traumatic Glenohumeral Dislocations

Although relatively uncommon, traumatic shoulder dislocations do occur, primarily during collision sports. The incidence is as high as 7% in young athletes participating in ice hockey.20 In addition, up to 40% of all primary shoulder dislocations occur in patients younger than 22 years.20 AP, axillary, and lateral views of the shoulder always should be obtained because associated fractures of the gle-
noid rim or Hill-Sachs lesions may occur. Magnetic resonance imaging (MRI), MR arthrography, or computed tomography arthrography may demonstrate a Bankart lesion or labral detachment (Fig. 2). Intra-articular contrast medium can be used to outline and properly visualize the labrum; without contrast medium, these structures cannot be fully evaluated. Labral injury or detachment usually denotes concomitant injury of the associated capsuloligamentous structures, which can result in distinct instability patterns, depending on the region of capsulolabral injury.4,6,17

Recurrent instability after a traumatic injury in the skeletally immature patient is common; rates range from 25% to 90% in adolescents and up to 100% in patients with open physes.21,22 Surgical intervention may be indicated when symptoms of instability persist despite 4 to 6 months of nonsurgical management—a brief period of immobilization followed by dynamic shoulder stabilization with deltoid, rotator cuff, and scapular muscle strengthening. Because recurrence rates are high in this population and because arthroscopic stabilization techniques have advanced, early stabilization increasingly is being recommended for athletes with traumatic instability with labral detachments or bony Bankart lesions.

Arthroscopic techniques now appear to produce functional results comparable to those of open Bankart or anterior capsulolabral reconstruction procedures.23-29 Arthroscopy has the potential advantages of better visualization of the capsulolabral complex and other intra-articular structures, less surgical dissection (which decreases scarring), less damage to surrounding tissues (which decreases morbidity), and earlier and more rapid rehabilitation with improved ROM, especially in external rotation.25,26,28 Arthroscopic suture anchors can be used for labral repair, and capsular pathology can be addressed concomitantly with suture capsulorrhaphy to maximize functional outcome and minimize the risk of recurrence (Fig. 3).

Postoperative shoulder immobilization is generally maintained for the first 10 to 14 days, followed by a progressive ROM and strengthening program. In patients with anterior instability, shoulder abduction and external rotation in the 90°-90° position overhead should be avoided in the early postoperative period. Therapy is directed at strengthening the rotator cuff, deltoid, and scapulothoracic muscles to provide dynamic stabilization of the shoulder. These techniques and protocols can achieve results comparable to those of traditional open stabilization techniques, so that the patient may be allowed to return to athletic activity at 3 to 6 months.23-29

**Medial Epicondylar Fractures**

Avulsion fractures of the medial epicondyle result from extreme valgus loads or violent muscle contractions during the throwing motion and commonly occur in adolescents as the medial epicondyle begins to fuse.11,21 Patients may report feeling a “pop” or “giving way” of the elbow, followed by acute pain; they also may describe locking or catching of the elbow. Examination reveals tenderness and swelling over the medial epicondyle with decreased ROM and valgus instability.11 Plain radiography shows avulsion of the medial epicondylar apophysis with varying degrees of displacement, depending on the force of the trauma.10,11 Type 1 fractures (a large fragment that may involve the entire epicondyle) occur in younger children, and type 2 fractures (small fragments) in adolescents older than 15 years of age with fused physes.10,11

Treatment is guided by the extent of fracture displacement. Minimally displaced fractures are treated with immobilization for 2 to 3 weeks, followed by a rehabilitation protocol, including protected active and active-assisted ROM exercises.10,11 Nonunions have been reported as a result of inadequate immobilization and activity modification because repetitive traction from resumed throwing leads to residual motion and stress at the fracture site, inhibiting physeal fusion. Late surgical excision may be indicated for pain. For patients with fractures displaced >5 mm, valgus stability should be tested clinically and, if necessary, should include valgus stress radiography. A medial joint line opening >2 to 3 mm is considered abnormal. In the presence of instability or marked rotation or displacement of the medial epicondyle fragment, surgical realignment by open reduction and internal fixation (with smooth Kirschner wires) is indicated to restore valgus stability. Anatomic reduction may prevent late sequelae, such as radiocapitellar degenerative changes.10,11,21

**Chronic Overuse Injuries**

Although skeletally immature athletes sustain a variety of acute shoulder and elbow injuries, most of these are chronic overuse injuries second-
ary to cumulative stresses from repetitive overhead throwing motion. Chronic injuries occur predominantly in baseball players, but participants in other sports involving similar overhead activity, such as football, tennis, swimming, or volleyball, also are susceptible. These injuries occur in specific patterns depending on the nature of the repetitive stresses and the developmental anatomy of the athlete.

Injuries of the Shoulder

Shoulder and elbow injuries increase in frequency during the mid to late teenage years. As the athlete matures and gains strength, the shoulder is subjected to greater stresses during the throwing motion. The most common overuse injuries include Little League shoulder, rotator cuff tendinitis, and glenohumeral instability—antero-, posterior, and multidirectional.

Little League Shoulder

Little League shoulder is epiphysiolysis of the proximal humerus secondary to repetitive microtrauma from overhead activity. Patients present with diffuse shoulder pain that is worse with throwing. A recent increase in the throwing regimen often precedes the onset of symptoms. Findings include tenderness and swelling over the anterolateral shoulder, with weakness on resisted abduction and internal rotation. External rotation contractures with decreased internal rotation also may develop. Radiographs usually reveal proximal physeal widening, best appreciated on an AP view taken with the shoulder in external rotation. Depending on the severity of the condition, radiographs also may demonstrate metaphyseal demineralization and fragmentation coupled with physeal irregularity and periosteal reaction.

Treatment involves an initial period of 2 to 3 months of rest and activity modification, followed by a progressive throwing program. The protocol calls for a light tossing schedule and gradually progresses with increasing distance and velocity. This protocol has shown excellent results, with up to 91% of patients remaining asymptomatic. Because of the great remodeling potential of the proximal humerus, long-term consequences are rare. However, problems can occur and may include premature physeal closure with resultant humeral length discrepancy or angular deformity, as well as subsequent Salter-Harris fractures of the proximal humeral epiphysis.

Factors that contribute to the development of Little League shoulder include excessive throwing, poor technique, and muscle-tendon imbalance. Coaches, trainers, and parents should be aware of the American Academy of Orthopaedic Surgeons (AAOS) guidelines for pitching (Table 1). Developing proper throwing mechanics and limiting the number of pitches and innings thrown are crucial for preventing Little League shoulder. Control, not speed, should be emphasized in training regimens. In addition, educating coaches and players about appropriate stretching, strengthening, and conditioning and proper throwing mechanics is vital.

Rotator Cuff Tendinitis and Impingement

Adolescent overhead athletes—especially those involved in baseball, swimming, and tennis—often sustain tendinitis or strains of the rotator cuff as a result of outlet impingement, cumulative tensile overload, and instability associated with internal impingement. Patients with rotator cuff damage usually present...
with anterolateral shoulder pain that worsens with continued activity. In addition, they may report mild stiffness and weakness in the involved extremity. Physical examination should include provocative impingement maneuvers and testing of ROM because active internal rotation may be present secondary to a tight posterior capsule.\textsuperscript{32,33} The Neer impingement sign is pain elicited by forcing the arm into a position of maximal forward elevation. The Hawkins impingement sign is pain elicited by forcible internal rotation with the arm forward elevated to 90°, which produces pain when the supraspinatus tendon impinges on the coracoacromial ligament or anterior acromion. Pain also may be present with resisted supraspinatus testing, although significant weakness is not typically noted unless an underlying tear is present.

Examination for concomitant glenohumeral instability is important because treatment must be geared toward all etiologic factors. Standard radiographic studies, including AP, outlet, and axillary views, typically do not show any marked osseous abnormalities. MRI is the imaging study of choice for evaluation of rotator cuff damage. Increased signal in the tendon and inflammation in the sub-acromial space may be noted within the insertion of the supraspinatus tendon, in cases of tendinitis. MRI also may show evidence of partial or full-thickness tears (Fig. 5), although these are not commonly observed in adolescents.\textsuperscript{2}

Initial treatment of rotator cuff injury is nonsurgical, consisting of rest, ice, nonsteroidal anti-inflammatory drugs (NSAIDs), and physical therapy. The physical therapy program focuses on ROM and strengthening of the shoulder muscles to correct underlying muscular imbalance and to provide dynamic glenohumeral stability. Proper rehabilitation is crucial not only to relieve pain and expedite return to play but also to prevent progression to partial or full-thickness tears that might require surgical intervention. Stretching is important to establish and maintain full ROM, especially in patients with tight posterior capsules with limited internal rotation. A strengthening program is instituted to increase strength in the rotator cuff as well as in the scapular stabilizers. During the acute phase of tendinitis, exercises should be performed below shoulder level to avoid rotator cuff outlet impingement, with gradual progression as symptoms de-

<table>
<thead>
<tr>
<th>Age</th>
<th>Maximum Pitches per Game</th>
<th>Maximum Games per Week</th>
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<tr>
<td>8-10</td>
<td>52 ± 15</td>
<td>2 ± 0.6</td>
</tr>
<tr>
<td>11-12</td>
<td>68 ± 18</td>
<td>2 ± 0.6</td>
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<tr>
<td>13-14</td>
<td>76 ± 16</td>
<td>2 ± 0.4</td>
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<tr>
<td>15-16</td>
<td>91 ± 16</td>
<td>2 ± 0.6</td>
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<tr>
<td>17-18</td>
<td>106 ± 16</td>
<td>2 ± 0.6</td>
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Figure 4  Swimmers subject their shoulders to excessive forces during both (A) the front crawl-stroke (cuff impingement, arrows) and (B) the backstroke (anterior capsular tension). In panel B, the arrows indicate the pull of the rotator cuff on the proximal humerus. (Adapted with permission from Wilkens KE: Shoulder injuries: Epidemiology, in Stanitski CL, DeLee JC, Drez D Jr [eds]: Pediatric and Adolescent Sports Medicine. Philadelphia, PA: WB Saunders, 1994, p 181.)
subtle instability patterns. These patterns may be related to rotator cuff fatigue, to superior labral anterior-posterior (SLAP) lesions involving the superior biceps–labral anchor complex, or to true instability and are associated with articular-sided partial-thickness rotator cuff tears. Arthroscopic acromioplasty is rarely performed alone in this population; rather, subacromial bursectomy and débridement are usually accompanied by procedures that address the associated damage (ie, débridement of partial-thickness rotator cuff tears and repair of SLAP/labral lesions).36 Progressive ROM and strengthening exercises may be initiated early after surgery. As a general rule, however, arthroscopy should be a last resort in the treatment of rotator cuff injuries in the adolescent athlete and undertaken only when specific, clearly defined damage can be addressed.

Anterior Glenohumeral Instability

Anterior instability usually results from chronic overload injuries in the athlete engaged in overhead sports. Excessive, repetitive external rotation during the overhead motion places tremendous stress on the anterior capsular and ligamentous structures, causing microtrauma that leads to ligamentous laxity. Initially, the rotator cuff and periscapular muscles compensate. However, these dynamic stabilizers fatigue with repeated activity, and anterior glenohumeral translation ensues, with subsequent development of instability. Secondary impingement of the rotator cuff anteriorly against the coracohumeral arch during forward flexion may occur, causing tendinitis or even undersurface tears.31 Furthermore, as the humeral head translates anteriorly with shoulder abduction and external rotation, internal impingement of the rotator cuff also may occur35 (Fig. 6). Normally, with the shoulder in the apprehension position, the distance between the rotator cuff and the posterosuperior glenoid rim is small. As the static stabilizers become lax and the dynamic stabilizers fatigue, increased anterior glenohumeral translation with the arm in the apprehension position pinches the cuff against the posterosuperior glenoid rim, producing internal impingement. Concomitant posterior capsular contractions caused by repetitive stress may further exacerbate the impingement.5,24

Athletes typically present with decreased throwing effectiveness and pain, especially during late cocking and early acceleration. They also may report a “dead arm.” On examination, load-and-shift (Fig. 7) and fulcrum tests may not demonstrate anterior laxity. Mild anterior apprehension with a positive relocation test may be present, indicating internal impingement. Loss of internal rotation also may be present, secondary to a tight posterior capsule.5,6,17 Athletes with associated rotator cuff damage may have appropriate findings. Usually, in the absence of a traumatic injury, plain radiography shows no significant abnormalities. MRI may show increased signal within the posterior cuff, consistent with fraying in cases of internal impingement, and if MRI is performed with contrast medium, it may show redundancy in the anterior capsule. Usually, labral damage is not present unless there has been a traumatic episode. Routine use of MRI for instability secondary to overuse is not needed unless the clinician suspects associated damage.

Treatment of anterior instability begins with an initial period of rest followed by physical therapy and a home exercise program that emphasizes strengthening and conditioning of the rotator cuff, deltoid, and scapular muscles. Both concentric and eccentric exercises are included as well as stretching of the posterior capsule if tightness is present. Improper throwing mechanics also must be corrected. Athletes are allowed to return gradually to throwing once stability, strength, and endurance have im-

Figure 5 Oblique coronal MRI scan of the shoulder after intra-articular injection of gadolinium, demonstrating partial-thickness undersurface rotator cuff tear (arrow). (Reproduced with permission from Kingston S: Diagnostic imaging of the upper extremity, in Jobe FW [ed]: Operative Techniques in Upper Extremity Sports Injuries. St. Louis, MO: Mosby, 1996, p 35.)
proved (usually within 3 months). With well-supervised physical therapy, most will be able to return to their prior level of activity in 6 months.2,37

If symptoms persist despite 4 to 6 months of well-supervised nonsurgical management, surgery may be indicated. Arthroscopy may reveal stretching of the inferior glenohumeral ligament and anterior capsule, labral fraying, or undersurface cuff tears.38,39 Debridement alone of the rotator cuff and posterosuperior glenoid is inadequate to address the underlying pathology; either open or arthroscopic anterior capsuloligamentous reconstruction is recommended for the best functional outcomes. An arthroscopic anteroinferior suture capsulorrhaphy is often sufficient to address the underlying damage, and current arthroscopic techniques have results comparable to those of open stabilization.29,36 Arthroscopy allows excellent visualization of the capsulolabral complex with minimal invasiveness, which can decrease morbidity and, more important, minimize external rotation loss postoperatively, which is critical in the overhead athlete. The lax inferior glenohumeral ligamentous complex and anteroinferior capsule are imbricated arthroscopically and tightened using multiple nonabsorbable sutures. Suture anchors may be placed along the glenoid rim to repair a labral detachment as well as to perform capsular plication24-27 (Fig. 3, C).

Postoperative isometric strengthening exercises are started early. Sling immobilization may be discontinued after 10 to 14 days, followed by progressive ROM and strengthening exercises. The deltoid, rotator cuff, and scapular muscles are targeted to provide dynamic stability and restore normal glenohumeral and scapulothoracic rhythm. Return to full, unrestricted

Figure 6  Progression of injury in internal impingement. A, The normal position of the humeral head in the glenoid during abduction to 90° in the scapular plane and maximal external rotation. B, Anterior translation (curved arrow) leads to subluxation of the humeral head and hyperangulation. C, This in turn leads to skeletal, labral, and tendinous lesions. Inset: The posterosuperior region of the glenoid (broken line) is where impingement occurs. (Reproduced with permission from Jobe CM, Pink MM, Jobe FW, Shaffer B: Anterior shoulder instability, impingement, and rotator cuff tear: Theories and concepts, in Jobe FW [ed]: Operative Techniques in Upper Extremity Sports Injuries. St. Louis, MO: Mosby, 1996, p 175.)

Figure 7 Load-and-shift test for anterior instability of the shoulder. With the patient seated, the examiner stabilizes the scapula with one hand and then applies a compressive force to the glenohumeral joint (arrows) and measures anteroposterior excursion (dotted lines). (Adapted with permission from McFarland EC, Shaffer B, Glousman RE, Conway JE, Jobe FW: Anterior shoulder instability, impingement, and rotator cuff tear: Clinical and diagnostic evaluation, in Jobe FW [ed]: Operative Techniques in Upper Extremity Sports Injuries. St. Louis, MO: Mosby, 1996, p 185.)
activity may take up to 6 to 12 months in the throwing athlete.

**Posterior Glenohumeral Instability**

Although not as common as anterior pathology, posterior instability is increasing in incidence as a result of chronic microtrauma to the posterior structures from repetitive overhead activity. Less commonly, a single traumatic episode may result in posterior capsular injury and subluxation, which may be missed if lateral and axillary radiographs are not obtained.\(^{20}\) Repetitive eccentric contraction during the deceleration and follow-through stages of throwing stretches the posterior capsule and produces microtears within the posterior cuff. Together, these factors can contribute to development of posterior instability.\(^{37,40}\) Typically, athletes present with pain during the deceleration phase of throwing, and pain may be elicited on examination with the arm in flexion, adduction, and internal rotation as the shoulder is posteriorly subluxated. Usually, in the absence of a posterior labral tear, neither plain radiography nor MRI shows any damage.

Initial treatment is nonsurgical and includes physical therapy to strengthen the posterior rotator cuff and scapular muscles, especially the infraspinatus, teres minor, and posterior deltoid. Proper throwing mechanics are emphasized along with leg and trunk strengthening to transfer some of the throwing stresses to the lower extremities. Usually, athletes are able to return to throwing after 4 to 6 months of rehabilitation. Recurrent or recalcitrant symptoms may require surgical intervention, with either open or arthroscopic posterior capsulorrhaphy to imbricate the redundant posterior capsule.\(^{31,42}\)

**Multidirectional Shoulder Instability**

Multidirectional instability (MDI) is characterized by symptoms of subluxation in more than one direction (anterior, posterior, or inferior) in the absence of a major traumatic event. Commonly, MDI affects athletes participating in sports that involve repetitive shoulder abduction and external rotation. Competitive swimmers, especially those swimming the butterfly stroke, and gymnasts often exhibit symptoms of MDI.\(^{2,31,37}\) Affected athletes typically possess underlying physiologic glenohumeral laxity that is exacerbated by repetitive microtrauma or by a traumatic insult, resulting in inability to maintain dynamic stability. Athletes may report a dead arm as well as a sensation of the shoulder dislocating and spontaneously reducing. Symptoms may be vague but usually correlate with the direction of instability. Athletes with anterior instability describe pain with the arm in the overhead, abducted, and externally rotated position. Those with posterior instability typically report pain with the arm in the forward-elevated and internally rotated position, such as when pushing open heavy doors. Patients with inferior instability may report discomfort when they carry heavy objects with the arm at the side. Occasionally, secondary rotator cuff symptoms also may be reported in conjunction with instability.\(^{31}\)

On physical examination, generalized ligamentous laxity may be present, with findings such as elbow and metacarpophalangeal joint hyperextension. The affected shoulder demonstrates increased glenohumeral translation in multiple directions. Comparing the affected shoulder with the contralateral shoulder is mandatory, and there may be multiple positive findings on load-and-shift, relocation, and fulcrum tests and apprehension maneuvers. Typically, a sulcus sign significant for inferior laxity is also present. It is important to determine the direction or directions of increased glenohumeral translation that actually replicate the patient’s symptoms because laxity does not necessarily indicate instability. Imaging studies are often unremarkable; plain radiographs usually show no osseous abnormalities unless the patient has had an actual dislocation, in which case a humeral head or glenoid defect may be observed. MRI arthrography with intra-articular contrast medium may show a redundant or patulous capsule with increased capsular volume, usually with no evidence of labral damage.

Initial treatment consists of rest and wet heat before, and ice after, activity. Most importantly, the patient should begin rehabilitation that emphasizes strengthening of the rotator cuff, deltoid, and scapulothoracic musculature to provide dynamic stability. Surgery is indicated when there are residual symptoms after a minimum of 6 months of therapy. Usually, the loose redundant capsule is reconstructed and imbricated in the direction or directions of predominant instability (anterior, inferior, or posterior, or combinations of these). Because current arthroscopic capsulorrhaphy techniques can achieve results similar to those of open inferior capsular shifts, these are typically preferred in overhead athletes.\(^{43,44}\) Thermal energy to “shrink” the redundant capsule is not indicated, given the failure rates for MDI;\(^{45-47}\) rather, suture capsulorrhaphy techniques to eliminate redundancy by imbricating the capsule and reducing its overall volume are preferable. Occasionally, these techniques are augmented with suture anchors along the glenoid rim for additional fixation.\(^{43,44}\) Suture capsulorrhaphy may be accomplished for the anterior and posterior capsule as well as the rotator interval, depending on the nature of the injury.

Patients should be counseled regarding treatment goals, including initial shoulder “tightening,” during which the shoulder is immobilized for a period of 2 to 4 weeks while gentle isometric exercises are performed. This is followed by gradual increase in ROM and strengthening over an ex-
tended period, with return to unrestricted activity by 6 months.

Injuries of the Elbow

Elbow injuries occur more frequently than shoulder injuries, with 50% to 75% of adolescent baseball players reporting elbow pain. Most of these injuries result from chronic repetitive stresses; they can be limited by decreasing the frequency and duration of throwing and by improving pitching mechanics. Although these injuries are most common in pitchers, they also occur frequently in other overhead athletes.

Little League Elbow

Initially described as an avulsion fracture of the medial epicondyle, Little League elbow is a general term relating to several abnormalities in the elbow of the young overhead athlete, including medial epicondylar avulsion, medial epicondylar apophysitis, and accelerated apophyseal growth with delayed closure of the epicondylar growth plate. Little League elbow results from repetitive valgus stresses and tension overload of the medial structures. Repetitive contraction of the flexor-pronator musculature stresses the chondro-osseous origin, leading to inflammation and subsequent apophysitis. Affected athletes are usually younger than age 10 years and typically report a triad of medial elbow pain, decreased throwing effectiveness, and decreased throwing distance. Patients may exhibit medial swelling, focal tenderness over the medial epicondyle, and occasional flexion contractures. Although results of plain radiography are sometimes normal, radiographic changes include irregular ossification of the medial epicondylar apophysis early in the disease process, followed by accelerated growth, marked by apophyseal enlargement, separation, and eventually fragmentation.

Generally, treatment consists of 2 to 4 weeks of rest and NSAIDs, followed by stretching and strengthening exercises of the elbow, with gradual return to throwing at 6 weeks if the athlete is symptom free. Occasionally, symptoms may persist for extended periods, typically because of inadequate rest or activity modification. In these instances, brief splint or cast immobilization may be necessary, and the patient should not resume throwing until the following season. Other factors contributing to exacerbation of symptoms include a high number of pitches thrown and innings pitched as well as improper throwing mechanics, all of which should be addressed and monitored closely in young overhead athletes.

Ulnar Collateral Ligament Injuries and Valgus Instability

UCL injuries are uncommon in skeletally immature athletes. Patients with this injury report medial elbow pain that is exacerbated during the late cocking and acceleration stages of throwing. Examination for valgus stability is performed with the elbow flexed 25° to 30° to unlock the olecranon from its fossa as a valgus stress is applied; this maneuver tests the anterior band of the anterior bundle of the UCL. The posterior band is tested by the milking maneuver (Fig. 8), performed by pulling the patient’s thumb with the forearm supinated, shoulder extended, and elbow flexed more than 90°. Usually, results of plain radiography are normal unless late changes associated with chronic laxity and valgus extension overload have developed. Valgus stress views also may be obtained to assess stability; a medial joint opening >2 mm wide indicates instability (Fig. 9). However, MRI is more useful and provides good visualization of the UCL as well as of the surrounding structures.

Initial treatment of UCL injuries includes a short period of immobilization coupled with ice and NSAIDs to control pain. Once the acute inflammation subsides, a supervised ther-
apy program aimed at restoring flexibility, muscle tone, strength, and endurance is begun to provide dynamic elbow stability and strengthening. A hinged elbow brace may be worn for the first 6 weeks to protect against valgus stress. The flexor-pronator muscles should be targeted with specific therapy because they are important secondary dynamic stabilizers of valgus stress. In addition, a thorough evaluation of the athlete’s throwing motion is essential to identify improper mechanics that must be corrected to prevent further ligamentous injury.

Surgery is reserved primarily for the older athlete with valgus instability despite at least 6 months of nonsurgical management. Direct repair is indicated only in cases of epicondylar avulsions with good ligamentous tissue quality; otherwise, open graft reconstruction of the anterior bundle of the UCL is necessary to restore valgus stability. The technique has been well described in adult athletes. A palmaris longus autograft or a similar graft is used in a figure-of-8 construct through osseous tunnels in the medial epicondyle and proximal ulna. This technique has allowed most overhead athletes to return to previous levels of function.

Osteochondritis Dissecans

Usually, osteochondritis dissecans (OCD) affects adolescents older than age 13 years. It typically involves the lateral compartment, specifically the capitellum, and less commonly the radial head. The etiology is unknown but may involve microtraumatic vascular insufficiency from chronic compressive and rotatory forces as a result of repetitive throwing. OCD must be differentiated from Panner’s disease, a self-limiting osteochondroisis that occurs in younger patients. Unlike the pain in OCD, pain in Panner’s disease occurs acutely with fragmentation of the entire capitellar ossific nucleus. In addition, normal capitellar growth resumes after this initial fragmentation, with no residual deformity or late sequelae.

Patients with OCD usually describe an insidious onset of symptoms characterized by dull, poorly localized pain that is worse with activity and relieved with rest. Elbow swelling and flexion contractures may be
present, as well as locking and catching of the elbow as loose bodies develop. Initial results of plain radiography may be normal but usually show rarefaction and irregular ossification of the involved region. With disease progression, a demarcated island of subchondral bone may be observed, along with radial head enlargement. MRI is extremely useful and important in determining the size of OCD lesions as well as the presence of fragment separation or displacement.

Treatment depends on the stage and size of the lesion, and results are better in younger patients. Nondisplaced stage 1 lesions without chondral separation are treated with activity restriction, although brief immobilization may be required in selected cases. Protected-elbow ROM is maintained until radiographic follow-up demonstrates healing and revascularization. Most patients are able to resume throwing in 6 to 12 months. Management of stage 2 lesions with chondral fissuring or partial detachment is more controversial; recommendations range from nonsurgical management to fragment fixation and bone grafting. However, even with successful reattachment, subsequent collapse and degeneration may occur. Consequently, fragment excision with debridement and subchondral drilling to promote a reparative response has been advocated. Stage 3 lesions with complete detachment and displacement are treated similarly. Removal of loose bodies coupled with drilling or curettage appear to have the best results in returning patients to activity.

Appropriate postoperative therapy is important, but some patients still have residual loss of motion and pain with activity; others eventually may undergo late development of radiocapitellar degenerative changes.

Posterior Compartment Injuries

Injuries of the posterior compartment are uncommon and are secondarily to extension overload from repetitive triceps contraction during deceleration and follow-through. Childhood injuries usually involve the olecranon apophysis and osteochondrosis with irregular ossification. In older adolescents, injuries tend to progress to avulsion or stress fractures of the olecranon apophysis that result in physeal widening, delayed fusion, or fragmentation seen on plain radiography. As the athlete nears skeletal maturity, valgus extension overload from repetitive throwing leads to posteromedial impingement, with subsequent osteophyte formation on the olecranon that can potentially fragment and become loose bodies. Traction spurs also can develop on the olecranon tip, along with scar tissue within the posterior compartment. Symptoms of pain, locking, or catching within the elbow may result, especially during the acceleration and follow-through stages of throwing.

Physical examination usually shows pain on terminal extension secondary to posteromedial impingement. Valgus stability should be assessed to rule out associated UCL laxity that may predispose to valgus extension overload. AP and lateral radiographs usually demonstrate osteophytes along the posteromedial olecranon. MRI is useful for visualizing the associated soft-tissue structures, especially the UCL in cases of valgus laxity. MRI also is helpful in demonstrating the presence of intra-articular loose bodies.

Treatment is individualized, based on the nature of the injury and the patient's age. Younger patients with olecranon stress fractures and osteochondrosis may be treated with a period of rest and activity modification (4 to 6 weeks) followed by ROM and strengthening exercises. Patients with avulsion fractures displaced >2 mm usually respond to a period of splint or cast immobilization followed by progressive ROM and functional exercises. Small apophyseal fragments that do not compromise the extensor mechanism may be surgically excised in patients with recalcitrant symptoms. Large fragments displaced >2 to 4 mm usually require surgical reattachment to restore the extensor mechanism and to optimize functional results.

In older adolescents with posteromedial impingement, initial treatment is nonsurgical, with a period of activity modification, ice, and NSAIDs followed by a physical therapy program aimed at stretching and strengthening the elbow, coupled with endurance training. Therapies such as ultrasound, moist heat, and phonophoresis also may be used. Athletes with persistent symptoms despite nonsurgical management may be candidates for arthroscopic débridement with removal of osteophytes and loose bodies to relieve symptoms and increase motion. A progressive ROM and strengthening program is instituted early after surgery, with the goal of initiating a progressive throwing program at approximately 6 to 8 weeks.

Lateral Epicondylitis/Apophysitis

Athletes playing racquet sports are prone to lateral epicondylitis as a result of repetitive wrist extension, although other overhead athletes may have similar symptoms secondary to repetitive, eccentric contraction of the wrist extensors, especially during the follow-through phase of throwing. Repetitive microtrauma to the lateral epicondylar apophysis and extensor tendon origin leads to apophysitis in younger persons and to extensor tendinitis in older athletes. Typically, patients report pain at the lateral epicondyle and extensor origin that is exacerbated with activity. Physical examination usually reveals focal tenderness over the lateral epicondyle and extensor origin, in addition to pain on resisted wrist and finger extension. Typically, plain radiography does not reveal significant abnormalities, although widening or fragmentation of the apophysis may be seen in some patients.
In adolescents, treatment of lateral epicondylitis is primarily nonsurgical. An initial period of rest and activity modification with cessation of the offending activity is usually supplemented with ice and NSAIDs. Physical therapy aimed at stretching and strengthening the wrist extensors and forearm musculature is also recommended, coupled with correction of improper throwing or stroke mechanics and adjustment of equipment size (eg, racquet grip size). Counterforce bracing also may be added to decrease stresses on the extensor origin. In severe cases, a prolonged period of rest and activity modification may be necessary, as well as the judicious use of corticosteroid injections for recalcitrant symptoms in older athletes approaching skeletal maturity. Surgery for lateral epicondylar fractures is rarely necessary in the adolescent athlete. Surgery for lateral epicondylitis is primarily nonsurgical. Although mechanisms of injury in the adolescent and adult populations are similar, anatomic differences result in distinct injury patterns unique to the skeletally immature athlete. Evaluation of the athlete should begin with the patient’s age, handedness, sport, and position played. For overhead athletes, it is important to note the phase of the overhead motion that produces the symptoms, the number of pitches per game or number of competitions per week, and any recent changes in training and performance technique. The clinician should understand the functional anatomy of the shoulder and elbow as well as the biomechanics of the overhead throwing motion or stress unique to the sport (eg, baseball, swimming, racquet sports).

A variety of chronic overuse injuries can develop in the young athlete as a result of cumulative stresses from repetitive athletic activity. Acute shoulder dislocations and avulsion fractures of the medial epicondyle can lead to chronic instability. In general, symptomatic shoulder and elbow conditions respond well to nonsurgical treatment instituted at an early stage. To achieve the best outcomes, these injuries must be recognized, diagnosed, and managed promptly. Instruction in proper throwing mechanics coupled with careful attention to the number of pitches and innings thrown are important in preventing injury recurrence. The AAOS recommends limiting the number of pitches per game to 60 to 100, with no more than 30 to 40 in a single practice session. The AAOS further suggests that innings pitched be limited to 4 to 10 per week. Furthermore, sidearm throwing should be strongly discouraged because athletes who throw with a sidearm motion are three times more prone to injury than are those who use a more overhead technique.

Advancements in rehabilitation protocols and in surgical treatment of refractory symptoms have improved the restoration of function in throwing athletes. With further insight into the relevant anatomy, biomechanics, and pathophysiology, advancements can continue to be made in the nonsurgical and surgical management of these unique athletic injuries.

Summary

Injuries to the shoulder and elbow are becoming more common as increasing numbers of young athletes participate in highly competitive athletics. Although mechanisms of injury in the adolescent and adult populations are similar, anatomic differences result in distinct injury patterns unique to the skeletally immature athlete. Evaluation of the athlete should begin with the patient’s age, handedness, sport, and position played. For overhead athletes, it is important to note the phase of the overhead motion that produces the symptoms, the number of pitches per game or number of competitions per week, and any recent changes in training and performance technique. The clinician should understand the functional anatomy of the shoulder and elbow as well as the biomechanics of the overhead throwing motion or stress unique to the sport (eg, baseball, swimming, racquet sports).

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References